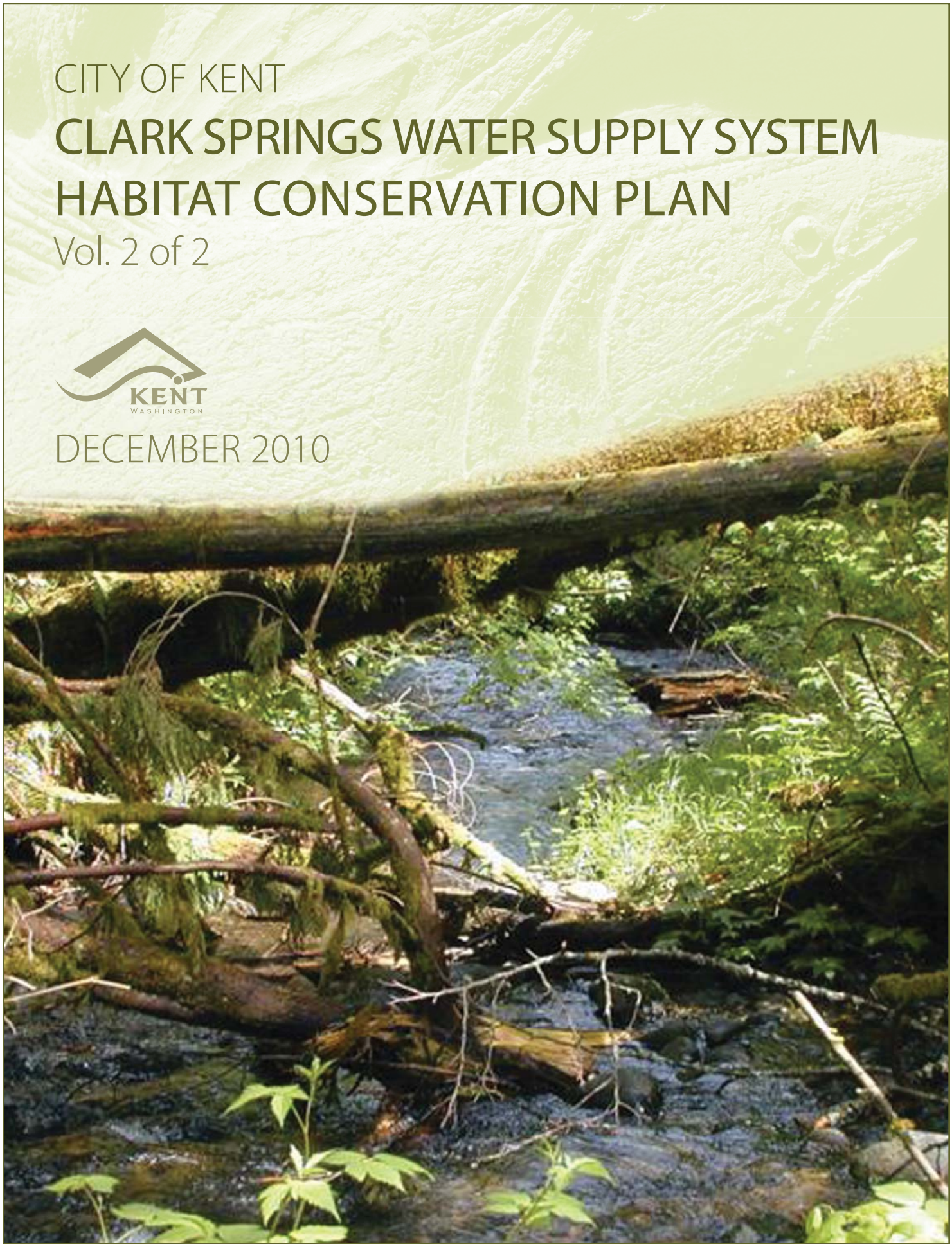
CITY OF KENT

# CLARK SPRINGS WATER SUPPLY SYSTEM HABITAT CONSERVATION PLAN

Vol. 2 of 2

KENT
WASHINGTON

DECEMBER 2010



enenG01401 1.10

# APPENDIX A

## Summary of Rock Creek Habitat Surveys

### Life Histories of Species of Concern

*Prepared by:*

Catherine Morello
Alan Olson
Dudley Reiser

R2 Resource Consultants, Inc.
15250 NE 95th Street
Redmond, WA 98052

January 24, 2006

*This page intentionally left blank.*

# APPENDIX A

## Life Histories of Species of Concern

The City of Kent is seeking an Incidental Take Permit (ITP) for nine fish species that could potentially be influenced by operations of their Clark Springs Water Supply System, Habitat Conservation Measures implemented under the City's Habitat Conservation Plan, or City operations within the Clark Springs watershed. The perennial headwaters for Rock Creek begin at RM 2.8 (262ndAvenue SE), located 0.2 miles to the east of the Clark Springs Watershed (Figure 1). This appendix contains life history summaries for each of the nine fish species. Eight of the species have anadromous life history forms, with three also exhibiting resident freshwater life history forms. The anadromous salmonids include Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*), chum salmon (*O. keta*), and steelhead trout (*O. mykiss*), and bull trout (*Salvelinus confluentus*). Resident salmonids include rainbow trout (*O. mykiss*), cutthroat trout, and bull trout. Other anadromous species proposed for coverage include the Pacific lamprey (*Lampetra tridentatus)* and river lamprey (*L. ayresi*).

### Chinook Salmon (*Oncorhynchus tshawytscha*)

Chinook, also referred to as king salmon, are the largest of the Pacific salmon species (Wydoski and Whitney 2003). They are differentiated into two juvenile behavioral forms, ocean-type and stream-type, based on their pattern of freshwater rearing. Juvenile ocean-type Chinook salmon migrate to the marine environment during the first year of life, generally within 3 to 4 months of emergence (Lister and Genoe 1970). Juvenile stream-type Chinook rear in fresh water for a year or more before outmigrating to the ocean. Within these two migrant designations many subtype variations have been described (Reimers 1971). Differences between these life history patterns are accompanied by differences in morphological and genetic attributes (Myers et al. 1998). Chinook salmon classification is

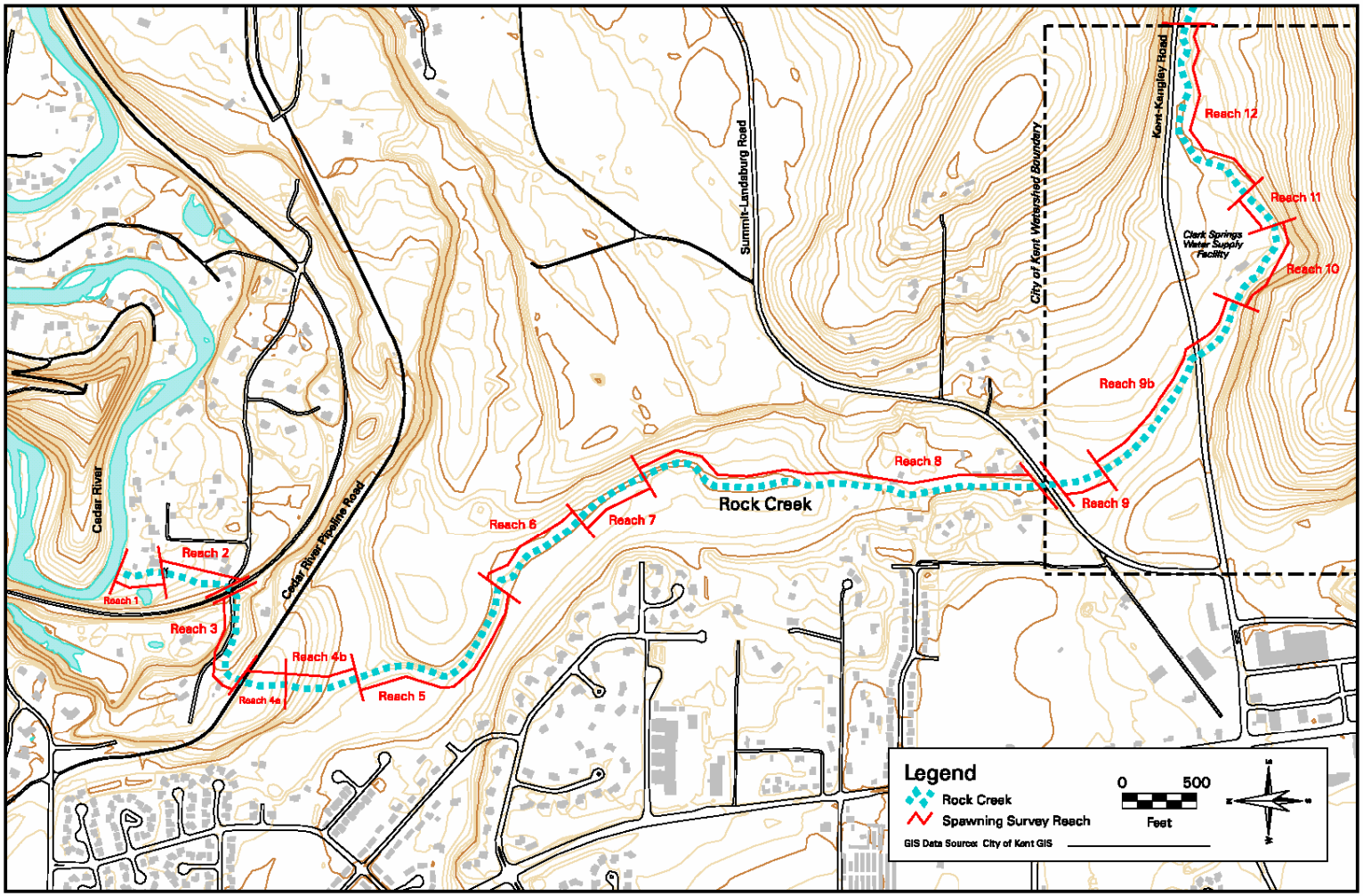



Figure 1. Map of Rock Creek survey reaches from the mouth to the northern boundary of the Clark Springs Watershed.

further divided by the timing of upstream migration (e.g., spring or fall/summer runs) (Beauchamp et al. 1983).

The principal race of Chinook salmon present in the Cedar River is summer/fall ocean-type Chinook (WDF et al. 1994). Adult summer/fall Chinook salmon enter freshwater at the Chittenden Locks between June and September with peak migration in mid-August (Warner and Fresh 1999).

Spawning in the Cedar River has occurred from as early as mid-August to as late as mid-November (Burton et al. 2004). Peak spawning typically occurs during early- to mid-October (City of Seattle 1999; WDF et al. 1994). According to Burton et al. (2004) the majority of Cedar River Chinook use mainstem habitats for spawning with a small proportion using tributaries. Adult Chinook salmon have been observed in the lower reaches of Rock Creek. These fish are believed to be strays from the Cedar River as no recent (1999-2004) spawning activity has been observed in Rock Creek (MCS Environmental 2003; R2 Resource Consultants 2004; R2 Resource Consultants 2005; Burton et al. 2004). Historical sources of Chinook distribution information do not agree on the upstream extent of utilization in Rock Creek. However, they do suggest that Chinook passage may have been historically limited by the old (replaced in 2004) culvert at SE 248th Street or the culvert present at the Seattle Pipeline crossing at River Mile 0.25 (WDFW 2005 and Streamnet 2005).

During upstream migration, pools greater than 3.3 feet in depth and instream cover are important habitat features utilized by adult Chinook and other anadromous salmonids for holding and resting (WFPB 1997). Adult Chinook select spawning sites based on substrate composition, cover and water quality and quantity. Owing to the larger size of Chinook salmon, larger gravels 0.75 to 4.0 inches (1.9 to 10.2 cm) in diameter are utilized for spawning (Raleigh et al. 1986). Chinook spawn over a range of water temperatures varying from 5.6 to 13.9°C (42 to 57°F) (Bjornn and Reiser 1991). Water velocity has been proposed as the most important variable in selection of spawning areas by Chinook salmon

(Raleigh et al. 1986), with an optimal range of approximately 1.0 to 3.0 ft/sec (Spence et al. 1996). Chinook salmon redds constructed in the Cedar River may be adversely affected by concurrent or subsequent spawning activity by sockeye salmon. Burton et al. (2004) reported that superimposition of Chinook redds by sockeye redds was observed in all five survey years (1999-2003) with superimposition rates generally increasing with sockeye escapement. However, impacts to incubating Chinook eggs and fry survival are unknown. In City of Seattle (2005), regional salmon experts suggested that sockeye competition was not likely to be an important factor affecting Chinook spawning success. Similar to other Pacific salmon species, Chinook die after spawning.

Incubation of Chinook eggs and yolk absorption by alevins (salmon larvae) in the redd require 4 to 6 months depending upon water temperatures (Healey 1991; City of Seattle 1999). Fry emergence and outmigration to Lake Washington usually begins in January. Based upon downstream trapping in the lower Cedar River, young-of-the-year Chinook demonstrate a bimodal outmigration to Lake Washington during the winter and spring (Seiler et al. 2005). The first pulse of fry (less than 60 mm in length) migrates shortly after emergence between January and mid-April. The second pulse of juvenile fish migrates as fingerlings (60 to 120 mm in length) between mid-April and July. While the majority of Cedar River Chinook tend to migrate as part of the earlier pulse of fry, the proportion of the population that migrates during each of these pulses varies from year to year. Flow appears to be an important factor influencing the two migration patterns (Seiler et al. 2005). Years with higher winter flows tend to have a higher proportion of Chinook migrating as fry rather than fingerlings. It has also been hypothesized that the availability of fry habitat has influenced the ratio of fry and fingerling migrants (WRIA 8 Steering Committee 2005). A reduction in the amount of fry habitat from historical conditions may have increased the proportion of fish that migrate to Lake Washington as fry.

Young-of-the-year Chinook may utilize a variety of water depths up to about 4.9 feet, but are more commonly found in shallower water approximately 0.8 to 2 feet in depth and associated with gravel, cobble, vegetation, and other debris that provides cover (Bjornn and Reiser 1991; Raleigh et al. 1986). Pools and runs are preferred habitat types, but pocket

water and riffles may also be utilized (Bjornn and Reiser 1991). Preferred substrate sizes depend upon the size of the fish, which utilize the interstices between substrate particles as cover. Fry can utilize coarse gravel up to 2 inches in diameter while larger fish may need cobbles greater than 3 inches in diameter (Bjornn and Reiser 1991). High levels of embeddedness from sand or silt, which fills the interstices, can make substrate unsuitable (Bjornn and Reiser 1991).

Chinook salmon in WRIA 8 exhibit an unusual life history trait: lake rearing. In contrast, most Chinook salmon spawn in rivers and streams that drain directly to the ocean. Consequently, patterns of lacustrine habitat use by young-of-the-year Chinook salmon are not completely understood. Passage through the Hiram Chittenden Locks occurs between May and mid-July with initiation of migration correlated with the time of the lunar apogee, when the moon is farthest from the earth in its orbit (DeVries et al. 2004). Neap (or minimum range) tides occur during apogee when the moon is at its farthest distance from the earth during its orbit; consequently this behavioral pattern may be an adaptation to increase the duration of fry presence in the estuary or reduce exposure to saline waters. The evolutionary advantages to this behavior pattern may be related more to historic rather than current conditions. Under a natural system, one without the locks, saline waters are able to extend further upstream during spring tides. Whether this behavior pattern is important to survival under the current hydraulic configuration of the system is uncertain.

An important feature of Chinook smolt passage at the Hiram Chittenden Locks is that the bimodal character of outmigration at the mouth of the Cedar River is not repeated. This suggests that Chinook fry from the Cedar River have a significant period of rearing in Lake Washington while fingerling smolts migrate through the lake relatively quickly. Studies by Fresh (2000) and Tabor et al. (2002) suggest that Chinook fry utilize the littoral zone through mid-May, but gradually utilize deeper waters further from the shoreline after this time. Orientation is more towards surface waters during the day, but towards the bottom of the water column at night (Tabor et al. 2002). In any case, it appears that the central portions of Lake Washington are little utilized by juvenile Chinook salmon (Fresh 2000).

Following entrance into the marine environment, juvenile Chinook disperse in nearshore waters and gradually into deeper portions of Puget Sound as they become larger; some Chinook may remain in Puget Sound through maturity while others eventually migrate to rear in the Straights of Juan de Fuca and Pacific Ocean (Kerwin 2001; Simenstad et al. 1982; Quinn 2005). Little is known about the specific distribution of Cedar River Chinook salmon in the Pacific Ocean. The City of Seattle (1999) suggested the distribution was likely to be similar to that of ocean-type Chinook of the region as described by Healey (1991). Healey (1991) suggested that most ocean-type Chinook remain on the continental shelf within 1,000 km of their natal stream.

Cedar River Chinook are considered part of the Puget Sound Evolutionarily Significant Unit (ESU). Overall, abundance of Chinook salmon in this ESU has declined substantially, and both long- and short-term abundance exhibit predominately downward trends. One factor negatively affecting the Chinook population in the Cedar River basin is land use practices. Lack of pool habitat, bank hardening features, loss of floodplain connectivity and a reduction in forest cover are all examples of factors affecting Chinook salmon populations (Kerwin 2001).These factors have led to this ESU being listed as threatened under the ESA in March of 1999 (64 FR 11481). Based upon data provided by WDFW (Foley 2006, personal communication), the escapement run size averaged approximately 449 fish from 1988 through 2005, while from 1964 to 1987 it averaged approximately 920 fish (Figure 2).

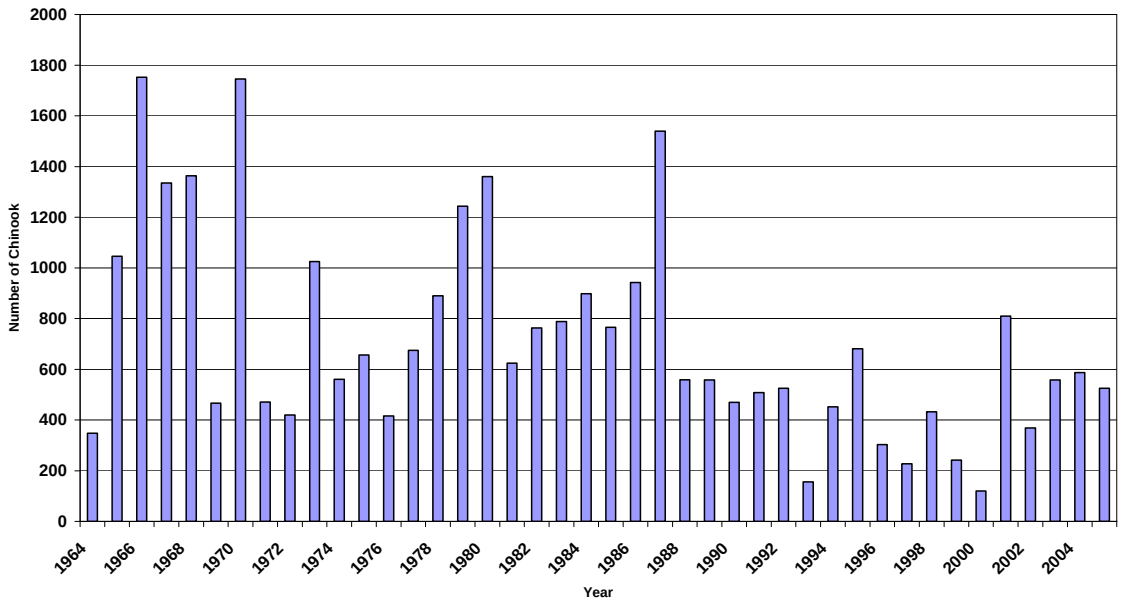



Figure 2. Estimated Chinook salmon escapement to the Cedar River 1964 to 2005. Data Source: Foley 2006, personal communication.

## Bull Trout (*Salvelinus confluentus*)

Bull trout, along with Dolly Varden (*Salvelinus malma*), are members of the char family. These two species are similar in coloration, morphology, and life history, making distinction between the two species difficult without the use of electrophoretic (i.e., DNA) samples or measurements of morphometric characteristics (WDFW 1998). The State of Washington has established identical protective measures and management for the two species. Within the Puget Sound region bull trout exhibit resident, anadromous, and adfluvial life history strategies (64 FR 58910). Bull trout spawn in cold, clear streams with complex channel characteristics. Juvenile rearing in streams occurs for 1 to 4 years. The two migratory forms then begin to move downstream to take up residence in lakes (adfluvial) or nearshore marine areas (anadromous). Maturity occurs at age 4 to 7 years with spawning migrations to the natal stream. Unlike Pacific salmon, which spawn once then die, bull trout are iteroparous and repeat spawn annually or in alternate years.

Bull trout are native to the upper Cedar River Watershed upstream of Chester Morse Lake and Masonry pool. However, bull trout have rarely been observed in Cedar River reaches downstream of Masonry Pool: 1) one bull trout has been documented near the powerhouse at Cedar Falls during 1997 (City of Seattle et al. 1999); 2) three adult bull trout were observed in the tailrace to the Cedar Falls powerhouse during July 2000 (64 FR 58910); and 3) three adult char assumed to be bull trout were found in the tailrace to the Cedar Falls powerhouse during August 2003 (64 FR 58910).

There have been no reported observations of bull trout in Rock Creek. However, the USFWS believes conditions in Rock Creek "may come close to suitable spawning temperatures and that may provide thermal refuge for rearing or foraging during warm summer periods" (64 FR 58910).

Lake Washington, Lake Union, the lower Cedar River (downstream of Cedar Falls) and their associated tributaries are considered by the USFWS as part of the Lake Washington critical habitat subunit (CHSU) (69 FR 35768; June 25, 2004). This area is considered critical habitat because of its ability to support bull trout foraging, migration, and overwintering behavior. Core population areas such as the Stillaguamish, Snohomish, and Skykomish rivers are considered to be the most likely source of bull trout to utilize the Lake Washington CHSU. Bull trout have been captured and observed within and below the Ballard Locks and within the associated fish ladder (Goetz et al. 2004).

Bull trout in the Chester Morse CHSU utilize an adfluvial life history strategy. There are no upstream passage facilities at Chester Morse or Masonry Dams and Cedar Falls is considered a natural barrier to bull trout. Consequently, bull trout that actively migrate or are inadvertently washed downstream from the dams are considered lost to the Chester Morse population. In contrast to the Chester Morse population, bull trout that enter the Lake Washington Watershed by passing through the Hiram Chittenden Locks utilize an amphidromous life history strategy. Amphidromous bull trout home to and spawn in natal freshwater streams and rivers, but the adults then migrate to estuarine and nearshore marine areas for rearing or feeding. Amphidromous bull trout may also enter non-natal freshwater

systems, such as Lake Washington, to overwinter and rear. Reproducing populations of bull trout have not been confirmed in the lower Cedar River (Kerwin 2001).

Spawning in most bull trout populations occurs in September and October, though it may occur in August at elevations above 4,000 feet in the Cascades and as late as November in coastal streams (Goetz 1989; Craig 1997). Most anadromous populations spawn only every second year, while resident char may spawn every year (Armstrong and Morrow 1980; USFWS 1998). Spawning habitat is characterized by low gradient, uniform flow, and a gravel substrate between 0.25 to 2.0 inches in diameter (Wydoski and Whitney 2003; Fraley and Shepard 1989). Groundwater influence and proximity to cover are also reported as important factors in spawning site selection (Fraley and Shepard 1989). Studies conducted throughout the species range indicate that spawning occurs in water from 0.75 to 2.0 feet deep (Wydoski and Whitney 2003; Fraley and Shepard 1989) and often occurs in reaches fed by streams, or near other sources of cold groundwater (Pratt 1992).

Rieman and McIntyre (1993) indicate that optimum bull trout embryo incubation temperatures are between 2 and 4ºC. These relatively cool incubation temperatures mean that bull trout generally require a long period of time from egg deposition until emergence. Embryos incubate for approximately 100 to 145 days, and often hatch in late winter or early spring. The alevins remain in the streambed, absorbing the yolk sac, for an additional 65 to 90 days and emergence from the streambed occurs in late winter/early spring (Pratt 1992). Long incubation times may result in higher susceptibility to fine sediment levels in spawning substrates, but the extent to which they reduce embryo survival and affect bull trout populations is not entirely known (Rieman and McIntyre 1993).

Bull trout fry are usually found in shallow, slow backwater side channels and eddies, in close proximity to instream cover (Pratt 1984). These characteristics are similar to that reported for other species of salmonids (Fraley and Shepard 1989). Juveniles are primarily bottom dwellers and are found among interstitial spaces in the substrate (Fraley and Shepard

1989; Pratt 1992). Sub-adults are often found in deeper stream pools or in lakes in deep water with temperatures less than 15°C (Pratt 1992).

In the proposed rule for designating critical habitat (69 FR 35768), bull trout are described as opportunistic feeders that migrate between patches depending upon the available foraging opportunities. Consequently, habitat utilization during rearing can be variable and dependent upon available food sources. In a riverine or lacustrine setting, bull trout may forage on a variety a terrestrial and aquatic insects, zooplankton, and small fish. In Chester Morse Lake an important forage fish are pygmy whitefish (*Prosopium coulteri*) and sculpin (*Cottus* spp.) (City of Seattle et al. 1999). In marine nearshore areas, bull trout forage on Pacific herring (*Clupea pallasii*), surf smelt (*Hypomesus pretiosus*) and sandlance (*Ammodytes hexapterus*) (Goetz et al. 2004). There are a number of potential forage fish species within Lake Washington for bull trout including longfin smelt (*Spirinchus thaleichthys*), juvenile salmonids, sculpins, perch (*Perca spp*), pumpkinseed (*Lepomis gibbosus*), and three-spine stickleback (*Gasterosteus aculeatus*). However, contents from one stomach of a bull trout captured in Lake Washington contained longfin smelt (Berge 2004, personal communication).

Five Distinct Population Segments (DPS) of bull trout (Klamath River, Columbia River, Jarbidge River, Coastal-Puget Sound, and St. Mary-Belly River) were listed as threatened under the ESA by the USFWS on October 28, 1999. These population segments are disjunctive and geographically isolated from one another with no genetic interchange between them due to natural and man-made barriers. Bull trout populations in the Cedar River Watershed as well as all Pacific Coast drainages in western Washington are part of the Coastal-Puget Sound DPS. Dolly Varden were likewise proposed as threatened under the ESA due to their similarity of appearance to bull trout (66 FR 1628). The WDFW includes bull trout as a State Candidate species. Candidate species include fish and wildlife species that the WDFW will review for possible listing as State Endangered, Threatened, or Sensitive.

## Coho Salmon *(Oncorhynchus kisutch)*

Coho salmon populations exist as far south as the San Lorenzo River, California and north to Norton Sound, Alaska (Sandercock 1991). Coho salmon are one of the most popular and widespread sport fishes found in Pacific Northwest waters. Rock Creek coho salmon appear to be typical of Puget Sound stocks with regard to their life history, which includes approximately eighteen months spent in freshwater followed by approximately eighteen months in saltwater (or up to three years; Weitkamp et al. 1995).

Adult coho enter freshwater at the Hiram Chittenden Locks during late August to mid-November (City of Seattle et al. 1999) and migrate up the Cedar River from early September through late January (Figure 3). River flow and temperature have been found to be important factors in the timing of river entry (Weitkamp et al. 1995). Spawning generally occurs in Rock Creek from late October to early March (WDF et al. 1994, R2 Resource Consultants 2004). The duration of egg incubation and the early rearing of alevins is dependent upon water temperatures (Sandercock 1991). Fry emergence timing in the Cedar River basin has not been specifically studied, but is believed to occur from early March through late May with peak emergence during April (City of Seattle et al. 1999).

Sandercock (1991) has reviewed coho salmon life history and habitat utilization traits. Juvenile coho salmon generally remain in freshwater for one year, but may occasionally extend their freshwater rearing period for an additional year or more, usually as a result of poor growth. Coho salmon fry are territorial while feeding during daylight hours on aquatic and terrestrial insects and their various larval stages. Territories may occur in both riffle and pool habitats, but pools are preferred. The size of a territory is dependent upon fish size, food density, and potential threats. Territories are smaller when food density or the potential for threats from other fish and predators is higher. In contrast, territories become larger as fish size increases. Stream complexity increases the number of available territories. This is especially true during the winter because juvenile coho move closer to cover in the form of logs, rootwads, debris and overhanging vegetation as water temperatures decrease (Bustard and Narver 1975). Individual coho salmon that lose during competitive interactions or grow

Figure 3. Likely freshwater life history periodicity of sockeye salmon, coho salmon, and Chinook salmon, in the Cedar River Watershed, Washington. Source: City of Seattle et al. (1999) and Wydoski and Whitney (2003).

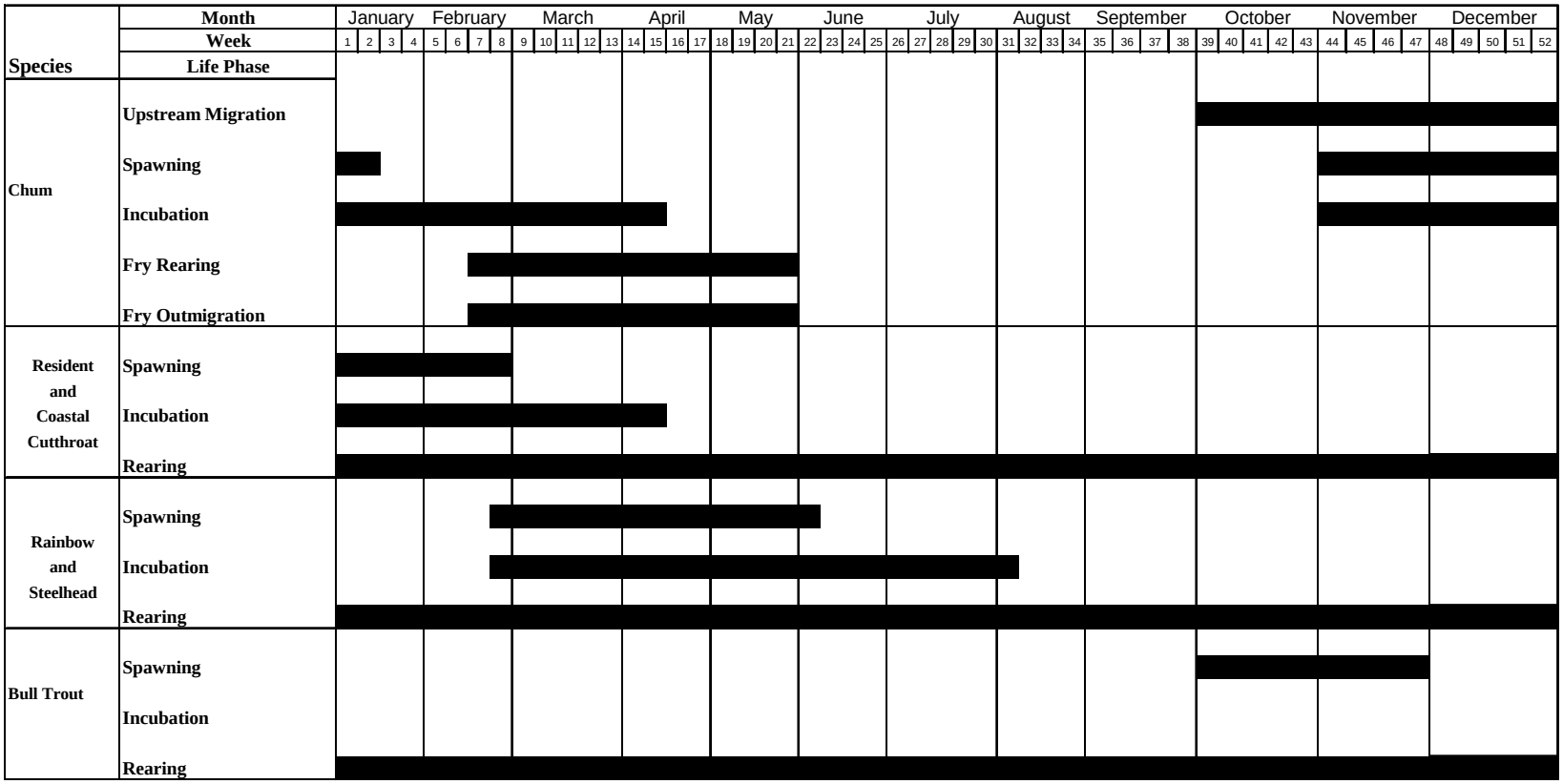



Figure 3. (cont.) Likely freshwater life history periodicity of chum salmon, cutthroat trout, rainbow and steelhead trout, and bull trout in the Cedar River Watershed, Washington. Source: City of Seattle et al. (1999) and Wydoski and Whitney (2003).

too large for the available habitat are often displaced, usually to locations farther downstream. Consequently, a gradual movement of some individuals from upstream spawning grounds in tributaries (e.g., Rock Creek) to downstream or mainstem areas (e.g., the Cedar River) is a typical pattern.

Coho salmon undergo smoltification during the spring, usually as one-year old fish. At this time, juveniles begin to lose their parr marks and become silvery in color. Territorial behavior and the tendency to hold position in the current diminish and are replaced by schooling behavior and downstream movement. Goetz et al. (1997) observed coho smolts moving through the Hiram Chittenden Locks from late April to early July with peak counts during mid- to late-May.

Coho spawning in Rock Creek occurs predominately in the upper reaches of the stream (Reaches 8 through 12- R2 Resource Consultants 2004) (Figure 1). These reaches also have excellent juvenile rearing conditions with relatively low velocities and high levels of cover. WDFW has also reported observations of juvenile and adult coho use during early 2000 within Georgetown Creek downstream of the culvert at Kent-Kangley Road (KCDNR 2001). Although no stream gage data were available for Rock Creek during this time period, based upon the results of stream flow modeling (Appendix E), average flows during the coho spawning period of October 1975 to January 1976 were the third highest of the of the 45 year period simulated. The available information suggests that the typical spawning distribution extends to just above the City of Kent's Clark Springs System where Rock Creek begins to parallel the Kent – Kangley Road; adult coho salmon may occasionally migrate further upstream if flows are suitable. It is unknown if migration of adult coho salmon upstream of the Clark Springs Watershed results in successful spawning that contributes to increased smolts outmigrating from the system.

Rock Creek coho salmon are identified by the WDFW as part of the Lake Washington – Cedar coho stock. Although the status of Cedar River coho salmon was determined to be healthy in 1992, due to recent downward population trends WDFW classified the stock as depressed in 2002 (WDFW 2002). NOAA Fisheries includes Rock Creek coho salmon in

the Puget Sound/Strait of Georgia ESU. Continued loss of habitat, extremely high harvest rates, and a severe recent decline in average spawner size are considered substantial threats to remaining native coho salmon populations in this ESU. Currently this ESU is not listed at threatened or endangered under the ESA, but is considered a candidate. Consequently, upon re-evaluation NOAA Fisheries may reconsider and propose to list the Puget Sound/Strait of Georgia population as threatened or endangered in the future (60 FR 38011).

## Sockeye Salmon (*Oncorhynchus nerka*)

Sockeye salmon exhibit a great variety of life history habits and characteristically use lacustrine (lake) habitat more than other salmon species. The Cedar River, one of the most productive salmon streams in the Puget Sound region, is home to the largest wild sockeye run south of British Columbia. There is debate whether historically sockeye were present in Lake Washington prior to introduction of the Baker River stock in 1935. Currently a "portable hatchery" has been operated at the base of the Landsburg Dam on the Cedar River since 1991 and the city of Seattle has plans to complete construction of a permanent hatchery facility in 2007 as part of its Cedar River Watershed HCP. Sockeye fry releases from the temporary hatchery have averaged 9.7 million fish annually from 1995 to 2001 (WDFW 2003). However, there is debate as to whether increased sockeye production will negatively affect Chinook populations in the Cedar River basin.

Sockeye salmon begin to enter the Cedar River during late August or early September, continuing into January. Spawning takes place in mid-September to late December and occasionally through January. Peak spawning takes place in mid- to late October (Gustafson et al. 1997; R2 Resource Consultants 2005). The duration of sockeye egg incubation is temperature dependent, but is generally longer than other salmon species (Burgner 1991). Rock Creek is one of the tributaries most heavily utilized by spawning sockeye in the Cedar River (WDF et al. 1994). Sockeye salmon have been observed to spawn up through Reach 12 in the Clark Springs Watershed, however the majority of spawning occurs in the lower Reaches 1 through 4.

Sockeye egg incubation, fry emergence, and early rearing are believed to be similar to that described in City of Seattle et al. (1999). Egg incubation occurs over a 2 to 3 month period. Following hatching, alevins remain in nest pockets for an additional 2 to 4 months prior to emergence. Emergence begins in late January and continues through May with the peak of the migration occurring during late March and early April. After emergence fry migrate quickly downstream. Sockeye outmigration from an artificial spawning channel on the lower Cedar River peaked from 26 April through 10 May (R2 Resource Consultants 2000). Juvenile sockeye rear in Lake Washington for 12 to 14 months, undergo smoltification during early spring and migrate through the Ballard Locks to Puget Sound between April and June.

In a 1969 letter co-signed by the directors of the Washington Department of Fisheries and Department of Wildlife, it was reported that 100,000 to 200,000 kokanee eggs were annually planted in Rock Creek, but the duration and outcome of the egg plantings was not described. Apparently the plantings were not successful because no spawning runs of kokanee have ever been reported for Rock Creek and no kokanee have been observed during recent spawning surveys sponsored by the City of Kent.

The sockeye in Rock Creek are considered by the Washington Department of Fish and Wildlife (WDFW) to be part of the Cedar River sockeye run, a component of Lake Washington sockeye. The Lake Washington sockeye escapement goal has been met two of the last four years. Although adequate fish were counted at the Ballard Locks to allow a Lake Washington sport fishery during 2004, relatively low numbers of spawning sockeye were observed in the Cedar River and Rock Creek. NOAA Fisheries does not consider the Cedar River sockeye stock to constitute an Evolutionarily Significant Unit (ESU) under the Endangered Species Act (ESA), and therefore it is not listed as threatened or endangered at this time.

## Chum Salmon *(Oncorhynchus keta)*

Chum salmon, known for the large teeth and calico-patterned body color of spawning males, have the widest geographic distribution of any Pacific salmonid (Johnson et al. 1997). In

North America, chum range from the Sacramento River in Monterey, California to Arctic coast streams (Salo 1991). Adult Chum salmon typically return to freshwater in October and November and spawn in the lower reaches of rivers from early December to early February (WDF et al. 1994). Preferred spawning areas are in groundwater-fed streams or at the head of riffles (Grette and Salo 1986). In general, chum salmon are reported to spawn in shallower, low-velocity streams and side channels more frequently than other salmon species (Johnson et al. 1997). The length of incubation of the eggs is influenced primarily by water temperature. For example, eggs at 15°C hatch approximately 100 days before eggs incubated at 4°C.

Juvenile chum salmon, like ocean-type Chinook, have a short freshwater residence and an extended period of estuarine residence, which is the most critical phase of their life history and often determines the size of subsequent adult returns (Johnson et al. 1997; Grette and Salo 1986). Chum fry in the middle Green River, a nearby watershed, were found to be present starting from the middle of March (Jeanes and Hilgert 2000). Peak abundance occurred during May, and continued through the end of the study in June. However, peak abundance was most likely influenced by large hatchery releases. Throughout the Jeanes and Hilgert (2000) study chum fry length remained fairly constant, indicating a short residence in freshwater.

Simenstad et al. (1982) reports that in the estuary, eelgrass (*Zostera* spp.) habitats may be particularly preferred by juvenile chum salmon. Juvenile chum may remain in the brackish water habitat of an estuary for several days to 2 months, moving offshore as food resources decline in the summer (Grette and Salo 1986). Simenstad et al. (1982) found chum salmon generally moved offshore at a size of 50-160 mm FL. Chum populations are often limited in Puget Sound river systems by the quantity or quality of available estuarine habitat because of their dependency on estuaries as rearing habitat. Little suitable estuarine habitat remains in the Lake Washington drainage for rearing juvenile chum salmon (Kerwin 2001). Chum salmon mature at 2 to 6 years of age, most commonly at 3 or 4 (Salo 1991).

Chum salmon have occasionally been observed in the Cedar River drainage, however native populations were all but extirpated in 1917 by the diversion of the river into Lake Washington. Only seven chum fry were captured in the Cedar River screw trap during the 2004 season (Seiler et al. 2005). In comparison, over 6,000 Chinook fry were captured during the same period. Adult chum salmon have been observed recently in Rock Creek and Mercer Slough, and possibly in Bear Creek and other tributaries, however the extent of any spawning is unknown (R2 Resource Consultants 2005; KCWLD 2004).

The WDFW (1992) does not identify chum salmon spawning in the Lake Washington Watershed as a stock. However, the Lake Washington Watershed is in the Puget Sound/Strait of Georgia ESU defined by NOAA Fisheries. Commercial harvest of chum salmon has been increasing since the early 1970s throughout this ESU. This increased harvest, coupled with generally increasing trends in spawning escapement, provides compelling evidence that chum salmon are abundant and have been increasing in abundance in recent years within this ESU (Johnson et al. 1997). The National Marine Fisheries Service concluded that this ESU is not presently at risk of extinction, and is not likely to become endangered in the near future (63 FR 11778).

## Steelhead and Rainbow Trout (*Oncorhynchus mykiss*)

Steelhead trout are rainbow trout that display an anadromous life history pattern. Steelhead, displaying perhaps the most diverse life history pattern of all Pacific salmonids, reside in most Puget Sound streams. Their historic native distribution extended from northern Mexico to the Alaska Peninsula. Presently, spawning steelhead are found along the Pacific Coast from as far south as Malibu Creek, California (Busby et al. 1996). As with Chinook salmon, runs of steelhead trout are generally named for the season in which they occur or peak. There are two types of runs of Pacific Northwest steelhead, winter run fish migrate into freshwater during the fall and winter, while summer run fish enter freshwater during the spring and summer (Pauley et al. 1986). Within these groups, steelhead are further divided based on the state of sexual maturity when they enter freshwater. Stream-maturing steelhead (summer steelhead) enter freshwater in an immature life stage. Ocean maturing (winter steelhead) enter freshwater with well-developed reproductive tissues (Busby et al. 1996). In

the Lake Washington system, no summer steelhead stocks and one winter steelhead stock have been identified (WDF et al. 1994).

Adult steelhead are iteroparous (repeat spawners), and can spend a large percentage of their life (2-3 years) in saltwater (Emmett et al. 1991). Winter steelhead return to the Lake Washington drainage from mid-December to mid-May and spawn generally from early March to mid-June (WDF et al. 1994). Juvenile steelhead incubation rates vary according to numerous biotic and abiotic factors but generally require a relatively short incubation period compared to other salmonids. Fry emergence typically occurs from 30 to 60 days after spawning (Pauley et al. 1986).

Everest and Chapman (1972) found age-0 steelhead residing over cobbles in water velocities of less than 5ft/s and depths of 0.5 to 1.0 ft. Bisson et al. (1982) reported fry inhabiting riffles associated with large woody debris. In general, juvenile steelhead differ from Chinook and coho salmon in their extensive use of faster, shallower, and higher gradient locations in streams, although it is not clear that this habitat type is preferred (Everest and Chapman 1972). Most steelhead juveniles reside in freshwater from 1 to 4 years before migrating to saltwater, with the majority of hatchery stocks migrating to the ocean at the end of their first year (Pauley et al. 1986).

The Cedar River may be the only stream in the Lake Washington basin that is contributing natural production to the basin (City of Seattle et al. 1999). Cedar River steelhead spawn and rear in the mainstem and tributaries below Landsburg Diversion Dam. In particular, small perennial streams, like Rock Creek, contain good steelhead spawning habitat (City of Seattle et al. 1999). However, no adult steelhead have been observed during fall spawning surveys (R2 Resource Consultants 2004), and spring surveys have not been conducted. During 1984 to 1992 steelhead spawner escapement has only met the WDFW goat of 1,600 in one year, 1985. Escapement has ranged from 474 to 1,816 wild steelhead in the Lake Washington basin (WDF et al. 1994).

Cedar River steelhead have been classified by NOAA Fisheries as part of the Puget Sound ESU (1 of 15 west coast steelhead ESUs). Total run size for the major stocks of this ESU was estimated at 45,000; natural escapement was estimated at 22,000 steelhead (Busby et al. 1996). Upon review of the population, NOAA Fisheries indicated in 1996 that, in general, the entire Puget Sound ESU was not threatened at that time. However, on April 5, 2005 NOAA Fisheries accepted a petition to list this ESU under the ESA. The agency received the petition September 13, 2004 and subsequent to their review, NOAA Fisheries found that the petition to list Puget Sound steelhead presented substantial scientific and commercial information indicating that the petitioned action may be warranted. As a result, petition acceptance will re-initiate and update the prior status review. In 1994 the Washington Department of Fisheries (WDF) classified the stock as 'depressed' (WDF et al. 1994). This classification was made based on the short-term severe decline in spawner escapement and run size. Many other regional stream systems have also displayed a steady decrease in winter steelhead populations since the mid-1980s (Kerwin 2001).

## Coastal Cutthroat Trout (*Oncorhynchus clarki clarki*)

Natural coastal cutthroat trout (*O. clarki clarki*) habitat ranges from the Eel River of northern California to Prince William Sound in southern Alaska, rarely penetrating more than 100 miles inland (Behnke 2002; Johnston 1982). It is a common native species in western Washington, often referred to as sea-run cutthroat. The coastal cutthroat trout exhibits four life history variations: sea-run (anadromous), resident stream populations, fluvial populations and lake-adapted (adfluvial) populations (Behnke 2002). All variations may be exhibited within the same stream. While it is likely anadromous populations once existed historically in the Cedar River they are most likely not present in the Lake Washington watershed today. The cutthroat trout in Rock Creek are considered adfluvial fish from Lake Washington as there are no records of sea-run cutthroat use at the Ballard Locks (City of Seattle et al. 1999). These adfluvial cutthroat trout reside in Lake Washington and migrate in late winter into tributaries, including the Cedar River and Rock Creek, to spawn. Unlike salmon, cutthroat trout are iteroparous and do not necessarily die after spawning. Coastal cutthroat trout have a lifespan of seven to nine years and may spawn multiple times (Behnke

2002). Adult cutthroat trout will spawn in small streams, and fry tend to move to the stream margins after swim-up.

Coastal cutthroat trout exhibit early life history characteristics similar to coho salmon, whereby juveniles spend time rearing in natal streams before outmigration. Winter habitat for juveniles consists of pools and side channels in association with woody debris. Overall, little is known about the habitat use of sea-run cutthroat trout during their freshwater residency (Johnson et al. 1999). Coastal cutthroat trout are piscivorous in their feeding and may be one of the most important predators of sockeye and Chinook salmon fry in the Lake Washington watershed (WRIA 8 Steering Committee 2005; City of Seattle 1999).

Within Rock Creek, adult adfluvial cutthroat trout have been observed from its mouth upstream to above the City of Kent's Clark Springs System (Reach 12). Adult adfluvial cutthroat trout have been observed in Rock Creek as early as the third week in November through mid-February; however, most observations tend to occur in late-December into January. This periodicity corresponds more closely with the typical sea-run cutthroat spawning period described Wydoski and Whitney (2003) for western Washington.

Information collated by the KCDNR Committee (2001), notes the presence of resident cutthroat trout in Lake 12, observations of juvenile cutthroat between 262nd Ave SE and 268th Ave SE during March 1996, and adult cutthroat near RM 4.5 in 2000. The reach between 262nd Ave SE and 268th Ave SE is located near the perennial headwaters of Rock Creek east of the upper boundary of the Clark Springs watershed. In addition, reaches upstream and downstream of the wetlands associated with Rock Creek near RM 4.5 regularly go dry on a seasonal basis. This information suggests that the distribution of cutthroat trout, and perhaps other salmonids in Rock Creek, expands and contracts on a seasonal or annual basis depending upon the availability of suitable habitat conditions.

Considerable information exists for Puget Sound cutthroat trout, though little of that has been collected in a standardized manner and over a long enough time period to establish trends in populations (Leider 1997). However, the Lake Washington cutthroat trout is

considered by NOAA Fisheries to not warrant listing under the ESA at this time (64 FR 16397).

## Pacific Lamprey *(Lampetra tridentatus*)

Pacific lamprey inhabit coastal streams from southern California north to Alaska (Wydoski and Whitney 2003). Pacific lamprey have been documented present in the Cedar River below Landsburg Dam (City of Seattle et al. 1999). While no specific accounts of Pacific lamprey utilization of Rock Creek have been located, lamprey presence is considered likely. One lamprey was captured during electrofishing surveys in Rock Creek during August 2002, but its species was not identified.

In the Pacific northwest, adult Pacific lamprey enter freshwater in July to October, and overwinter to spawn in May when water temperatures are between 10°C and 15°C (Close et al. 1995, Wydoski and Whitney 2003). Both sexes construct a shallow nest in stream gravels (Morrow 1976), in flows 1.6 to 3.3 fps (Close et al. 1995). During mating, the female attaches herself to a rock with her oral sucker while the male attaches to the head of the female. The male and female coil together while the eggs and sperm are released. Fertilized eggs adhere to the downstream portion of the nest (Moyle 1976), which are then covered by the adults. The process is repeated several times in the same nest site, with death of the adults occurring shortly thereafter (Moyle 1976). Spawning Pacific lamprey are often observed during steelhead spawning surveys, and they frequently spawn in similar habitats (Jackson et al. 1996).

Larval lamprey, termed ammocoetes, swim up from the nest and are washed downstream where they burrow into mud or sand to feed by filtering organic matter and algae (Moyle 1976). Ammocoetes have been shown to select substrates that contain high amounts of silt, and decaying organic material (Potter 1980). The ammocoetes generally remain in freshwater for 4 to 7 years, moving from site to site (Wydoski and Whitney 2003). Such an extended freshwater residence makes them especially vulnerable to degraded stream and water quality conditions. Ammocoetes, similar to salmonids, are sensitive to dissolved

oxygen levels in streams. In a study by Close et al. (1995) low oxygen concentrations (7-10 mm Hg) caused ammocoetes to emerge from the substrate and die.

Pacific lamprey larvae transform into juveniles from July through October (Close et al. 1995). During the transformation from a microphagous feeding habit to an adult parasitic mode, ammocoetes undergo several obvious external changes, including development of an oral disk, modification of gill opening structures, and development of teeth, eyes, and fins. Internal changes are slower and more variable in their onset, including changes in hemoglobins and plasma proteins, as well as development of a foregut (Hardisty and Potter 1971).

It is thought that temperature cues are responsible for the synchronous onset (3-4 weeks) of the transforming stage (Hardisty and Potter 1971), but it is not clear at what temperature Pacific lamprey begin their transformation. After metamorphosis, macrophthalmia may remain in freshwater substrates for up to 10 months, then emerge and passively migrate downstream. Based on available information of other lamprey species, and passage data at dams in the Northwest, it appears that downstream movement primarily occurs at night, and deeper in the water column than other anadromous fishes (i.e., salmon).

Aside from sporadic accounts of juvenile lamprey attached to teleost (boney) fishes in freshwater environments, most information suggests that juveniles do not feed during downstream migrations. As many anadromous lamprey spend some time in estuarine environments, it is possible that osmoregulatory capabilities to a full marine environment develop only gradually. It has been noted that outmigrating Pacific lamprey near estuaries can attach themselves to salmon smolts (Starke and Dalen 1995).

Adult lamprey are known to be parasitic on teleost fishes in marine environments, but stomach contents from several species have also indicated a carnivorous or scavenging habit, suggesting a more predatory existence (citations in Hardisty and Potter 1971). They may remain in saltwater for up to 3.5 years (Close et al. 1995). Pacific lamprey return to freshwater in the fall, overwinter, and spawn in the spring (Close et al. 1995). They do not

feed during the spawning migration, and will die shortly after spawning. The spawned out carcasses provide important nutrients to the stream system, as well as dietary items for other fish, such as white sturgeon (Close et al. 1995). Pacific lamprey may reach a size of approximately 70-cm, or over 2 feet long, at maturity (Hart 1973).

## River Lamprey (*Lampetra ayresi*)

River lamprey exhibit life history characteristics similar to the Pacific lamprey. Furthermore, river lamprey juveniles are morphologically similar to Pacific lamprey, making positive distinction between the two species difficult (Wang 1986). The adult river lamprey is smaller than the Pacific lamprey, with a body length of only 30 cm, or slightly less than one foot (Hart 1973). River lamprey remain in the ocean for only about ten weeks (Kostow 2002). They remain very close to shore, near the rivers that produced them. The life span of river lamprey from metamorphosis to death after spawning is shorter than that of the Pacific lamprey, measuring approximately two years (Beamish 1980). No specific documentation has been found concerning river lamprey in the project area. However, similar to Pacific lamprey, it is likely the species may be present.

# REFERENCES

Armstrong, R. H. and J.E. Morrow. 1980. The Dolly Varden charr, *Salvelinus malma*. *In* Charrs, Salmonid Fishes of the Genus Salvelinus. Eugene K. Balon, editors. Dr. W. Junk bv Publishers. The Netherlands.

Beamish, R. J. 1980. Adult biology of the river lamprey (*Lampetra ayresi*) and the Pacific lamprey (*Lampetra tridentata*) from the Pacific coast of Canada. Canadian Journal of Fisheries and Aquatic Science 37:1906-1923.

Beauchamp, D. A., M. F. Shepard, and G. B. Pauley. 1983. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) – Chinook salmon. U.S. Fish and Wildlife Service, Division of Biological Services, FWS/OBS-82/11.6. U.S. Army Corps of Engineers, TR EL-82-4. 15 pp.

Behnke, R. J. 2002. Coastal Trout *Oncorhynchus clarki*. Chapter 4 of Behnke, R.J. Native Trout of Western North America. AFS Monograph 6.

Berge, H. 2004. Personal communication 11/15/04. A. Olson, R2 Resource Consultants.

Bisson, P. A., J. L. Nielsen, R. A. Palmason, and L. E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. Pages 62-73 *in* N. B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. Proceedings of a symposium held 28-30 October 1981. Western Division, American Fisheries Society, Portland, Oregon.

Bjornn, T. C. and D. W. Reiser. 1991. Habitat Requirements of Salmonids in Streams. *In* Pages 83-138 Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. W. R. Meehan, editor. Am. Fish. Soc. Spec. Pub. 19.

Burgner, R. L. 1991. Life history of sockeye salmon (*Oncorhynchus nerka*). Pages 1-118. *in* Pacific Salmon Life Histories. Groot, C. and Margolis, L., editors.

Burton, K., L. Lowe, and H. Berge. 2004. Cedar River Chinook salmon (*Oncorhynchus tshawytscha*) redd and carcass surveys: Annual Report 2003. Seattle Public Utilities, Seattle, Washington.

Busby, P. J., T. C. Wainwright, G. J. Bryant, L. Lierheimer, R. S. Waples, F. W. Waknitz, and I. V. Lagomarsino. 1996. Status review of west coast steelhead from Washington, Idaho, Oregon, and California. U.S. Dept. of Commer., NOAA Tech. Memo. NMFS-NWFSC-27, 261 p.

Bustard, D. R. and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada 32(5): 667-680.

City of Seattle, U.S. Fish and Wildlife Service, and National Marine Fisheries Service. 1999. Environmental assessment / Final Environmental Impact Statement for the proposed issuance of a permit to allow incidental take of threatened and endangered species. Cedar River Watershed draft Habitat Conservation Plan.

City of Seattle. 1999. Habitat Conservation Plan for the Cedar River Watershed. City of Seattle, Washington.

Close, D. A., M. Fitzpatrick, H. Li, B. Parker, D. Hatch, and G. James. 1995. Status report of the Pacific lamprey (*Lampetra tridentata*) in the Columbia River basin. Project No. 94-026, Contract No. 95B139067. Report to the U.S. Department of Energy, Bonneville Power Administration, Portland, Oregon.

Craig, S. D. 1997. Habitat conditions affecting bull trout, *Salvelinus confluentus*, spawning areas within the Yakima River Basin, Washington. Masters Thesis. Ellensburg, Washington, Central Washington University.

DeVries, P., F. Goetz, K. Fresh, and D. Seiler. 2004. Evidence of a Lunar Gravitation Cue on Timing of Estuarine Entry by Pacific Salmon Smolts. Trans. Am. Fish. Soc.: 133: 1379-1395.

Emmett, R. L., S. L. Stone, S. A. Hinton, and M. E. Monaco. 1991. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume II: species life history summaries. NOAA/NOS Strategic Environmental Assessments Division ELMR Report No. 8. Rockville, Maryland. 320 p.

Everest, F. H. and D. W. Chapman. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. Journal of Fisheries Research Board of Canada 29:91-100.

Foley, S. 2006. Excel Spreadsheet, Personal Communication. Alan Olson, R2 Resource Consultants.

Fraley, J. J. and B. B. Shepard. 1989. Life history, ecology and population status of migratory bull trout (*Salvelinus confluentus*) in the Flathead Lake and River systems, Montana. Northwest Science 63: 133-143.

Fresh, K. L. 2000. Use of Lake Washington by juvenile chinook salmon, 1999 and 2000. Proceedings of the chinook salmon in the greater Lake Washington Watershed

workshop, Shoreline, Washington, November 8-9, 2000, King County, Seattle, Washington.

Goetz, F. 1989. Biology of the bull trout *Salvelinus confluentus*, a literature review. Willamette National Forest. Eugene, Oregon. 53 p.

Goetz, F. A., E. Jeanes and E. Beamer. 2004. Bull trout in the nearshore, preliminary draft. U.S. Army Corps of Engineers, Seattle District.

Grette, G. B. and E. O. Salo. 1986. The status of anadromous fishes of the Green/Duwamish River system. Submitted to U.S. Army Corps of Engineers, Seattle District. Seattle, Washington. 213 p.

Gustafson, R. G., T. C. Wainwright, G. A. Winans, F. W. Waknitz, L.T. Parker, and R. S. Waples. 1997. Status review of sockeye salmon from Washington and Oregon. NOAA Technical Memorandum NMFS-NWFSC-33. December 1997. Seattle, Washington. 282 p.

Hardisty, M. W. and I. C. Potter. 1971. The general biology of adult lamprey. Pages 127-207 *in* M. W. Hardisty and I. C. Potter, editors. The biology of lamprey. Academic Press, London.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. 180. 740 pp.

Healey, M. C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). Pages 311-394 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press, Vancouver, British Columbia, Canada.

Jackson, A. D., P. D. Kissner, D. R. Hatch, B. L. Parker, M. S. Fitzpatrick, D. A. Close, and H. Li. 1996. Pacific lamprey research and restoration, Annual report. Prepared for the U.S. Department of Energy.

Jeanes, E. D. and P. J. Hilgert. 2000. Juvenile salmonid use of lateral stream habitats, middle Green River, Washington. Prepared for the U.S. Army Corps of Engineers, Seattle District.

Johnson, O. W., M. H. Ruckelshaus, W. S. Grant, F. W. Waknitz, A. M. Garrett, G. J. Bryant, K. Neely, and J. J. Hard. 1999. Status review of coastal cutthroat trout from Washington, Oregon, and California. U.S. Dept. Commer., NOAA Tech Memo. NMFS-NWFSC-37, 292 p.

Johnson, O. W., W. S. Grant, R. G. Cope, K. Neely, R. W. Waknitz, and R. S. Waples. 1997. Status review of chum salmon from Washington, Oregon, and California. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-32.

Johnston, J. M. 1982. Life histories of anadromous cutthroat trout with emphasis on migratory behavior. Pages 123-127 *in* E.L. Brannon and E.O. Salo, editors. Salmon and trout migratory behavior symposium. School of Fisheries, University of Washington, Seattle, Washington.

KCDNR (King County Department of Natural Resources). 2001. Known Freshwater Distribution of Chinook Salmon. GIS map prepared by Kin County Department of Natural Resources from information gathered by the WRIA 8 Technical Committee. URL: http://dnr.metrokc.gov/wrias/8/fish-maps/chinook/index.htm.

KCWLD (King County Water and Land Division). 2004. 2003 volunteer salmon watchers program, Lake Washington Watershed. King County, Washington.

Kerwin, J. 2001. Salmon and steelhead habitat limiting factors report for the Cedar-Sammamish basin (WRIA 8). Washington Conservation Commission. Olympia, Washington.

Kostow, K. 2002. Oregon lamprey: natural history status and analysis of management issues. Oregon Dept. of Fish and Wildlife. 48 p. plus figures and appendices.

Leider, S. A. 1997. Status of sea-run cutthroat trout in Washington. Pages 68 -76 *in* J. D. Hall, P. A. Bisson and R. E. Gresswell, editors. Sea-run cutthroat trout biology, management and future conservation. Oregon Chapter of the American Fisheries Society. Corvallis, Oregon.

Lister, D. B. and H. S. Genoe. 1970. Stream habitat utilization by cohabiting underyearlings of chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon in the Qualicum River, British Columbia. J. Fish. Res. Bd. Can., 27(7):1215-1224.

MCS Environmental, Inc. 2003. Rock Creek 2002-2003 salmonid spawning survey Kent, Washington. Prepared for the City of Kent. 8 p. plus appendices.

Morrow, J. E. 1976. The freshwater fishes of Alaska. Alaska Northwest Publishing Company, Anchorage, Alaska.

Moyle, P. B. 1976. Inland Fishes of California, sucker family. University of California Press, Los Angeles.

Myers, J. M., R. G. Kope, G. J. Bryant, D. Teel, L. J. Lierheimer, T. C. Wainwright, W. S. Grant, F. W. Waknitz, K. Neely, S. T. Lindley, and R. S. Waples. 1998. Status review of chinook salmon from Washington, Idaho, Oregon and California. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-35.

Pauley, G. B., B. M. Bortz, and M. F. Shepard. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) – steelhead trout. U.S. Fish and Wildlife Service biological report 82(11.62). U.S. Army Corps of Engineerss, TR EL-82-4.

Pratt, K. L. 1992. A review of bull trout life history. Proceedings of the Gearhart Mountain Bull Trout Workshop. Oregon Chapter of the American Fisheries Society.

Pratt, K. L. 1984. Habitat use and species interactions of juvenile cutthroat (*Salmo clarki lewisi*) and Bull trout (*Salvelinus confluentus*) in the upper Flathead River basin. Master's thesis, University of Idaho, Moscow.

Quinn, T. P. 2005. The Behavior and Ecology of Pacific Salmon and Trout. University of Washington Press, Seattle. 378 pages.

R2 Resource Consultants, Inc. 2000. Lower Cedar River side channel fry production from 1999 spawners. Final data report.

R2 Resource Consultants, Inc. 2004. Biological monitoring of Rock Creek, Washington. 2003-2004 salmonid spawning surveys. Prepared for the City of Kent, Washington.

R2 Resource Consultants, Inc. 2005. Rock Creek 2004 - 2005 Spawning Survey Report. Final Report to the City of Kent.

Raleigh, R. F., W. J. Miller, and P. C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: Chinook salmon. Biological Report 82(10.122). U.S. Fish and Wildlife Service.

Reimers, P. E. 1971. The length of residence of juvenile fall Chinook salmon in Sixes River, Oregon. Fish Commission of Oregon Research Division.

Rieman, B. E. and J. D. McIntyre. 1993. Demographic Habitat Requirements for Conservation of Bull Trout. USDA Forest Service. Intermountain Resarch Station. Gen. Tech. Report INT-302.

Salo, E. O. 1991. Life history of chum salmon (*Oncorhynchus keta*). Pages 233-309 *in* C. Groot and L. Margolis, editors. Life history of Pacific salmon, University of British Columbia Press, Vancouver, British Columbia.

Sandercock, F. K. 1991. Life History of Coho Salmon. Pages 397-445 *in* C. Groot and L. Margolis, editors, Pacific Salmon Life Histories.

Seattle Public Utilities. 2005. Cedar River Sockeye Hatchery Project Final Supplemental EIS. Seattle Public Utilities, Seattle, WA.

Seiler, D., G. Volkhardt, and L. Fleischer. 2005. Evaluation of downstream migrant salmon production in 2004 from the Cedar River and Bear Creek. Washington Dept. of Fish and Wildlife.

Simenstad, C. A.; K. L. Fresh; and E. O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of pacific salmon: an unappreciated function. Pages 34-64 *in* V. S. Kennedy, editor. Estuarine Comparisons. Academic Press, Inc., New York, New York.

Spence, B. C., G. A. Lomnicky, R. M. Hughes, and R. P. Novitizki. 1996. An Ecosystem Approach to Salmonid Conservation. Report Prepared by Management Technology. Sponsored by the National Marine Fisheries Service, U.S. Environmental Protection Agency, and the U.S. Fish and Wildlife Service. 356 pp.

Starke, G. M. and J. T. Dalen. 1995. Pacific lamprey (*Lampetra tridentata*) passage patterns past Bonneville dam and incidental observations of lamprey at the Portland District Columbia River dams in 1993. U.S. Army Corps of Engineers, Cascade Locks, Oregon.

Streamnet. 2005. Data Query for Chinook Salmon, Rock Creek, tributary to Cedar River. Downloaded on 1/20/05 from Streamnet. URL: www.streamnet.org.

Tabor, R. A. and R. M. Piaskowki. 2002. Nearshore Habitat Use by Juvenile Chinook Salmon in Lentic Systems of the Lake Washington Basin, Annual Report, 2001. U.S. Fish and Wildlife Service, Western Washington Office, Division of Fisheries and Watershed Assessment, Lacy, Washington. 56 pp.

U.S. Fish and Wildlife Service. 1998. Bull trout interim conservation guidance. U.S. Fish and Wildlife Service.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin Estuary and adjacent waters, California: A guide to the early life histories. Tech. Report 9 (FS/B10-4ATR 86-9). Prepared for the Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. URL: http://elib.cs.berkeley.edu/kopec/tr9/html/home.html.

Warner, E., and K. Fresh. 1999. Draft Lake Washington chinook salmon (Oncorhynchus tshawytscha) recovery plan. Prepared by the Muckleshoot Indian Tribe Fisheries

Department, Washington Department of Fish and Wildlife, and Squamish Indian Tribe Fisheries Department. 1 March 1999. Auburn, Washington. 117 p.

WDF (Washington Department of Fisheries), Washington Department of Wildife, and Western Washington Treaty Indian Tribes. 1994. 1992 Washington State salmon and steelhead stock inventory, Appendix 1: Puget Sound stocks, Hood Canal & Straight of Juan De Fuca volume. December 1994. Olympia, Washington. 424 p.

WDFW (Washington Department of Fish and Wildlife). 1998. Bull Trout and Dolly Varden, Appendix to the Washington State Salmonid Stock Inventory. Olympia, Washington.

WDFW (Washington Department of Fish and Wildlife. 2003. Hatchery and genetic management plan (HGMP). Washington Department of Fish and Wildlife. Olympia, Washington. 32 pp.

WDFW (Washington Department of Fish and Wildlife). 2002. Salmonid Stock Inventory (SASI) 2002. Lake Washington - Cedar Chinook. URL: http://wdfw.wa.gov/webmaps/salmonscape/sasi/full_stock_rpts/1144.pdf.

WFPB (Washington State Forest Practices Board). 1997. Standard Methodology for Conducting Watershed Analysis under Chapter 222-22 WAC, Version 4.0 Timber/Fish/Wildlife Agreement and WFPB, Olympia.

Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status review of coho salmon from Washington, Oregon, and California. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-24.

WRIA 8 Steering Committee. 2005. Proposed Lake Washington/Cedar/Sammamish Watershed Chinook Salmon Conservation Plan. Lake Washington/Cedar/Sammamish Watershed.

Wydoski, R. S., and R. R. Whitney. 2003. Inland fishes of Washington. University of Washington Press, Seattle.

*This page intentionally left blank.*

# APPENDIX B

## Summary of Rock Creek Habitat Surveys

*Prepared by:*

Alan Olson
Dudley Reiser

R2 Resource Consultants, Inc.
15250 NE 95th Street
Redmond, WA 98052

January 24, 2006

*This page intentionally left blank.*

# Summary of Rock Creek Habitat Surveys

Rock Creek, located southeast of the city of Maple Valley, Washington, is a tributary to the Cedar River entering at River Mile (RM) 18. The creek is approximately 7.4 miles in length and has a drainage basin of about 15.7 square miles. The perennial portion of the creek is spring-fed with its origin at approximately RM 2.8 in an area known as Clark Springs. From RM 7.2 to around RM 2.8, surface flow is often completely lost to groundwater, thus the stream is largely dry except during high flow periods. Median monthly discharge from 1986 to 1998 ranged from a low of 1.4 cubic feet per second (cfs) in October to 20.7 cfs in March (as measured at the Parshall flume near Hwy 516). Rock Creek has been described as having some of the highest quality aquatic habitat in the Cedar River drainage, and all of western King County (King County 1993). It is an important stream for salmonid species utilizing the Cedar River, including sockeye salmon (*Oncorhynchus nerka*), coho salmon (*O. kisutch*), rainbow trout (*O. mykiss*), and cutthroat trout (*O. clarki*). Chinook salmon (*O. tshawytscha*) have been infrequently observed in Rock Creek in recent years (R2 2004a).

Rock Creek has historically been surveyed several times in order to characterize aquatic populations, habitat and channel morphology (Jones and Stokes 1993; May 1998; Pentec Environmental 2001; MCS 2003; Priest and Berge 2002; R2 2004a; and R2 2004b; Williams et al. 1975). In particular, physical habitat surveys provide a basic understanding of the channel characteristics present that affect aquatic populations including salmon.

This document summarizes three Rock Creek habitat surveys: Jones and Stokes and Associates (Jones and Stokes 1993), Pentec Environmental (2001), and R2 (R2 2004b). All three of the habitat surveys were completed under similar environmental settings during fall low flow conditions. Individual stream reaches varied slightly between surveys, but in general each survey began near the mouth of Rock Creek and continued at least into the braided channel/wetland section below Summit-Landsburg Road. Different survey methodologies and objectives of the surveys' results make precise quantitative comparisons difficult. However, a qualitative comparison and discussion of results is presented.

## Jones and Stokes and Associates Habitat Survey (1993)

Jones and Stokes and Associates, Inc. (Jones and Stokes) surveyed Rock Creek in November 1991 as part of the Wilderness Retreat and Wilderness 50 environmental impact statement prepared for a proposed housing development (Jones and Stokes 1993). The survey began just above the mouth of Rock Creek at RM 0.03 and continued upstream to RM 1.16 just downstream of Summit Landsburg Road (Figure 1; Table 1). Jones and Stokes utilized a two-tier assessment approach including Level 1 and Level 3 survey protocols adopted by the King County Surface Water Management Division. The Level 1 survey utilized a methodology modified from the U.S. Forest Service Stream Habitat Classification and Inventory Procedures for Northern California (which was the basis for future methodologies

reported in WFPB 1997) (McCain et al. 1990). Specifically, Level 1 surveys consisted of the classification and measurement of individual habitat types or habitat units (HUs). HUs were classified as one of eight different habitat types, including high and low gradient riffles; backwater, corner, dammed, lateral scour and mid-channel pools; and riparian wetland. The length, average channel width and depth, and average wetted width and depth were measured for each classified habitat. Other habitat characteristics assessed included dominant channel substrates, riparian vegetation, shade and large woody debris. Large woody debris was tallied if it was a minimum of ten feet in length and had a diameter of at least ten inches. Results were provided as cubic yards of woody debris per mile.

Table 1. Stream survey reach lengths and breaks by surveyor in river miles (RM) and river kilometers (RK), Rock Creek, Washington, 2005.

| | RM | RK | Reach Length[1] (m) |
|---|---|---|---|
| **Jones and Stokes (1993)** | | | |
| Downstream | 0.03 – 0.32 | 0.05 – 0.51 | 464 |
| Proposed Development Area | 0.32 – 0.90 | 0.51 – 1.45 | 931 |
| Upstream | 0.90 – 1.16 | 1.45 – 1.87 | 421 |
| **Pentec Environmental (2001)** | | | |
| Reach 1-3 | 0.00 – 0.28 | 0.00 – 0.45 | 448 |
| 4b-7[2] | 0.33 – 0.85 | 0.54 – 1.36 | 826 |
| 8 | 0.85 – 1.52 | 1.36 – 2.45 | 1,088 |
| 9 | 1.52 – 1.78 | 2.45 – 2.87 | 415 |
| 10 | 1.78 – 2.74 | 2.87 – 4.41 | 1,540 |
| **R2 (2004c)** | | | |
| Reach 1-3 | 0.00 – 0.28 | 0.00 – 0.46 | 456 |
| 4a | 0.28 – 0.33 | 0.45 – 0.33 | 88 |
| 4b-7 | 0.33 – 0.90 | 0.33 – 1.45 | 907 |
| 8 | 0.90 – 1.52 | 1.45 – 2.46 | 1,005 |
| 9 | 1.52 – 1.93 | 2.46 – 3.11 | 651 |
| 10-13 | 1.93 – 2.75 | 3.11 – 4.43 | 1,312 |

1. These reach lengths were calculated directly from habitat survey data rather than a GIS.
2. R2 added the designation 4a to denote the portion of Reach 4 that could not be surveyed by Pentec due to landowner objections.

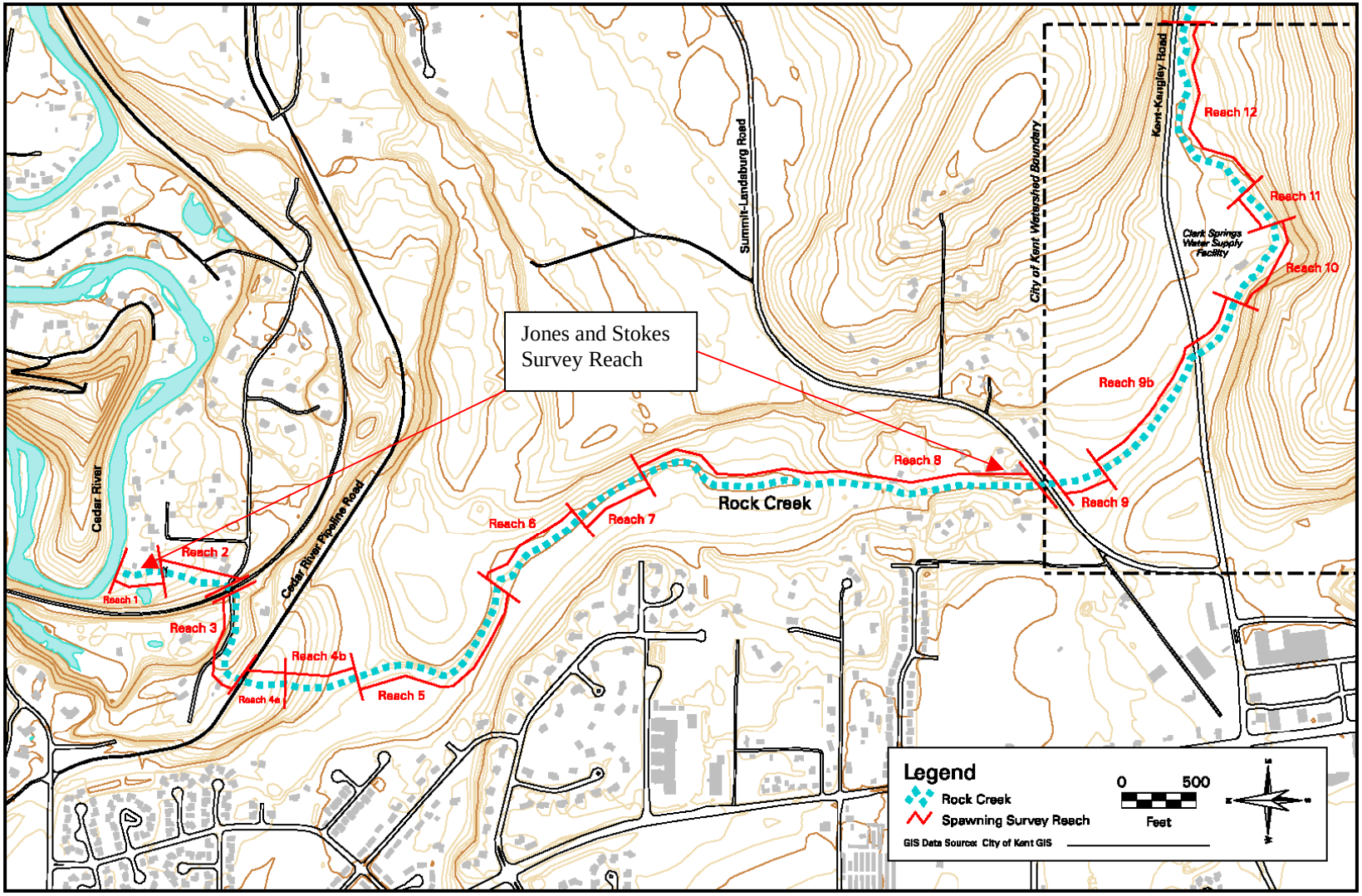



Figure 1. Map of Rock Creek habitat survey reaches utilized by R2 and Pentec, Washington, 2005. Adapted from R2 2004a.

The reach surveyed by Jones and Stokes downstream of the proposed development (near the mouth of Rock Creek to just above the Cedar River pipeline crossing) was classified as riffle-dominated. Jones and Stokes reported 50.7 percent high gradient riffle habitat (measured by area) and 39.0 percent low gradient riffle habitat in this section. The remaining 10.3 percent of the habitat consisted of pools. The stream gradient in this downstream reach (average 3.3%) is greater than the other survey sections (average of 2.5% for the proposed development section; average of 0.7% for upstream reach) resulting in a higher stream velocity. Some housing development had previously occurred along the stream banks, with removal of much riparian vegetation, lowering the density of large organic debris. However, bank and channel stability were found to be good. The substrate was a mixture of scattered embedded boulders with pockets of gravel/cobble substrates, with a particularly good patch of spawning gravel immediately upstream of Southeast 248$^{th}$ Street.

In the proposed development area (just above the Cedar River pipeline into the wetland below Summit Landsburg Road), Rock Creek exhibited a greater proportion of low gradient riffles and pools than in the downstream section. Jones and Stokes measured 52.1 percent low gradient riffle, 20.2 percent high gradient riffle and 27.7 percent pool habitat by area. This reach was described as having a good mixture of riffle and pool habitat. There was less development in this reach, and large organic debris densities increased in comparison to the downstream reach. Increased levels of large organic debris had caused some minor bank failure. Substrate sizes found in the lower portion of the project reach were similar to the downstream section; however, smaller substrates became increasingly dominant in the upstream portions of the proposed development segment.

Jones and Stokes classified nearly the entire habitat of the section above the proposed development (within the wetland below Summit-Landsburg road) as riparian wetland. This section was a complex of pool and low gradient riffle habitat, exhibiting a highly braided channel. The wide stream channel led to lower levels of streamside shading than within the proposed development reach and below. The substrate primarily consisted of gravel and sand overlain with silt and detritus. Areas of higher flows and the action of spawning salmon had uncovered the gravel in spots and Jones and Stokes identified this reach as some of the best coho spawning habitat in Rock Creek. This was the only section in which aquatic vegetation was found to be present.

The large organic debris density was reported by Jones and Stokes to be greatest upstream of the project area (1,983 cubic yards per mile of stream). The downstream and project sections contained 750 and 405 cubic yards per mile respectively.

The Jones and Stokes Level 3 survey consisted of a detailed study of channel morphology and aquatic habitat at twelve stations, or transects, within the Level 1 survey area. Level 3 transects provided cross sectional channel elevations, detailed substrate information, specific riparian characterization, stream discharge and macroinvertebrate information particular to each transect. Six of the transects were equally spaced within the project boundary and three transects each were located in the reaches upstream and downstream of the project site. As opposed to the more general Level 1 surveys, Level 3 surveys provided habitat data specific to transect locations.

### Pentec Environmental (2001)

Pentec Environmental (Pentec) surveyed Rock Creek between October and December of 2000 (Pentec Environmental 2001 and Pentec unpublished data). The survey began at the mouth of Rock Creek and continued upstream into the City of Kent watershed near RM 2.7 (Figure 1; Table 1). Pentec surveyors generally followed Washington State Watershed Analysis protocol as outlined in WFPB (1997). Each reach was broken into units from 100 to 500 feet in length. Each individual unit was then described by the following metrics: channel type, percent pool, average substrate characteristics, and wetted and bankfull widths. These metrics were compared to the matrix of properly functioning habitat condition indices provided in WFPB (1997) to obtain overall habitat ratings of good, fair, or poor (Table 2). Large woody debris surveys followed protocol described in Martin and Benda (2000). Results included woody debris and key piece density measured in pieces per channel width.

In Reaches 1 through 3 (from the mouth of Rock Creek upstream through the Cedar River pipeline crossing), Pentec reported Rock Creek as having good adult access to spawning gravel, spawning and incubation habitat, and winter rearing substrates (Table 2). Dominant substrates were found to be gravel and cobble. The section was rated poor overall for summer and winter rearing habitat because of the lack of pools (percent length and frequency), LWD (large woody debris), and off-channel habitat. Habitat area in lower three reaches of Rock Creek consisted of only 17.3 percent pool. Some residential housing and associated landscaping was present in this reach.

Pentec reported 13.0 percent of the habitat as pool, with 49 individual pools counted in Reaches 4b through 7 (Cedar River pipeline crossing to below the wetland complex). This section was rated overall as having good adult access to spawning gravel, spawning

Table 2. Fish habitat ratings, as ranked in WFPB 1997, for Rock Creek, Washington, 2000. Source: Pentec Environmental (2001).

| | **Summer/Winter Rearing Habitat** | | | | **Winter Rearing Habitat** | | **Adult Upstream Migration Habitat** | | **Spawning and Incubation Habitat** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Pools** | | **LWD/channel width** | | **Spawning** | | | | | | |
| **Reach[1]** | **Percent** | **Frequency** | **Debris** | **Key Piece** | **Substrate** | **Off-Channel** | **Holding Pools** | **Gravel Access** | **Gravel Presence** | **Gravel Quality** | **Fines** |
| 1 | Poor | Poor | Poor | Poor | Good | Poor | Poor | Good | Good | Good | Good |
| 2 | Poor | Poor | Fair | Poor | Good | Poor | Poor | Good | Good | Good | Good |
| 3 | Poor | Good | Good | Good | Good | Poor | Poor | Good | Good | Good | Good |
| 4 | Poor | Poor | Good | Poor | Good | Poor | Poor | Good | Good | Good | Good |
| 5 | Poor | Good | Good | Good | Good | Poor | Poor | Good | Good | Good | Good |
| 6 | Poor | Fair | Good | Good | Good | Poor | Poor | Good | Good | Good | Good |
| 7 | Poor | Fair | Good | Good | Good | Poor | Poor | Good | Good | Good | Good |
| 8 | Fair | Good | Good | Good | Poor | Fair | Poor | Good | Poor | Fair | Poor |
| 9 | Fair | Good | Good | Good | Good | Poor | Poor | Good | Good | Fair | Fair |
| 10 | Fair | Good | Good | Good | Poor | Fair | Poor | Good | Good | Good | Poor |

[1] See Figure 1 for Reach locations

and incubation habitat, and winter rearing substrate (Table 2). Gravel was the dominant substrate, with some cobble and boulders. This section was rated fair to good for summer and winter rearing habitat because the frequency of pools (percent length) was higher than in the lower reaches, and the section contained high levels of woody debris.

The upstream-most survey section, Reaches 8 through 10 had 49.0 percent pool as measured by area. In this reach, between Summit-Landsburg Road and the upstream end of the City watershed, summer and winter rearing habitat was rated as fair to good owing to high levels of woody debris and pool frequency, and because of the wetland-like characteristics of the channel (Table 2). This reach also had good access to spawning gravels, but only poor to fair spawning and incubation gravels due to high substrate embeddedness.

Large woody debris density was greatest in the middle reaches (4-7), measuring 532.7 pieces per mile. Pentec identified 261.9 pieces per mile in the upstream section (Reaches 8-10) and 203.6 pieces per mile in the lower section (Reaches 1-3). In comparison to WFPB (1997) metrics, throughout its course, Rock Creek lacked pool habitat area, specifically holding pools and off-channel rearing habitat.

### R2 Resource Consultants (2004)

The most recent survey of Rock Creek was performed by R2 Resource Consultants (R2) in November of 2004 to support an instream flow analysis (see Appendix F). R2's survey protocol was based on a modified Hankin-Reeves approach (Hankin and Reeves 1988). R2's survey began at the mouth of Rock Creek and continued upstream to approximately RM 2.7, and utilized approximately the same stream reach breaks as Pentec 2001 with in some cases, additional subdivisions (Figure 1; Table 1). R2 utilized the following habitat descriptions to delineate individual habitat units:

- Riffle – relatively shallow section of stream containing turbulent flows and swift water velocities;
- Run/Glide – area of slower moving water with little of no surface turbulence;
- Braided Channel – area of multiple complex split-channels;
- Pool – area exhibiting little or no velocity and no surface disturbance; and
- Cascade – area of steep gradient and fast, turbulent flow.

Each individual habitat unit was further quantified by length, width, depth and substrate characteristics. R2's protocol did not include a survey of large woody debris.

In Reaches 1 through 3, (the mouth of Rock Creek to the Cedar River pipeline crossing), the habitat in Rock Creek was primarily riffle (72.2%), followed by pool (8.8%), cascade (8.2%), braided channel (5.6%), and run/glide (5.2%). Dominant substrates in this section were gravel (42.7%) and cobble (34.5%) with some boulder (23.7%). Numerous sockeye salmon were observed spawning in this section during habitat surveys. Residential housing and associated lawns have increasingly occupied areas of the east bank within this section. Overall the stream channel in this section was confined and shallow, with good bank stability.

In Reaches 4 through 7, R2 calculated 86.7 percent riffle, 4.8 percent run/glide, 5.3 percent pool and 3.1 percent cascade habitat. This section is primarily undeveloped, with no residential housing located along the stream banks. Salmon fry were observed rearing in pools in this section. Substrates in this section were predominately gravel (38.0%) and cobble (33.2%) with lesser amounts of boulder and sand.

The upstream reaches (8-13) were lower gradient and exhibited slower stream velocities than the lower sections. The primary habitat unit in the upstream reaches was run/glide (47.5%) followed by braided channel (26.8%) and riffle (13.3%). Approximately 12.4 percent of the habitat was considered pool, and no cascades were present. This section is an extended wetland complex with a highly braided, wide channel. Portions of the braided habitat units had slow moving, pool-like qualities. Substrates in this reach were comprised of nearly equal amounts of sand (33.3%), silt (31.7%) and gravel (24.8%) with lesser amounts of cobble and boulder.

### Discussion

The above data provide a general characterization of the quality of habitat currently found in Rock Creek that should be useful for evaluating future conditions. The results indicate there is excellent salmonid spawning and incubation habitat downstream of the wetlands below Summit-Landsburg Road and excellent coho-rearing habitat within and upstream of the Summit-Landsburg Road. These conditions are maintained in part by the presence of forested riparian zones in Rock Creek, and their subsequent input of large organic debris, providing habitat and cover for salmonid species. In contrast, the surveys suggest that adult holding, juvenile rearing, and overwintering habitat are in short supply from Reach 1 through Reach 7 because of the general lack of large or deep pools and little off-channel habitat.

The habitat conditions in lower Rock Creek are in part a product of topographic features within the watershed. Jones and Stokes (1993) reported that stream gradients downstream of the proposed Wilderness retreat/Wilderness 50 development averaged 3.3 percent, those within the development reach averaged 2.5 percent, and those above the proposed development were 0.7 percent. In addition, much of the stream between Reaches 3 and Reach 7 was moderately to highly confined on one or both sides of the stream. This type of topography would tend to promote riffles if no instream structures are present (Montgomery and Buffington 1993). A number of events may have resulted in changes in channel morphology of Rock Creek between the surveys described above including flooding that occurred in November 1995 and a windstorm in December 2005 that added substantial amounts of large woody debris to Reaches 2 and 3 and initiated changes in the channel morphology and movement of channel substrate. In addition, mitigation measures for the replacement of the box culvert at SE 248th Street also resulted in the addition of large woody debris to Reach 2. The relatively high levels of large woody debris found in much of Rock Creek provide structure to the stream and have promoted the development of frequent, but relatively small pools.

The majority of Rock Creek, from its perennial source at Clark Springs to the mouth of the creek is currently protected from urban or residential development. This has resulted in a relatively pristine riparian corridor consisting of mature second-growth forest including Douglas–fir, western red cedar, western hemlock, big-leaf maple, red alder and black cottonwood (Jones and Stokes 1993). The entire Clark Springs Watershed from RM 1.5 to 2.7 is protected by the City of Kent as a water supply source. Although the proposed Wilderness Retreat/Wilderness 50 development was not implemented, King County purchased and converted these and other adjacent properties into the Rock Creek Natural Area.

There has been some residential development immediately downstream of the Summit-Landsburg Road and from the Cedar River pipeline to the mouth of the creek. Stream crossings occur at four locations within the perennial section of the stream: SE 248th Street, the Cedar River Pipeline, Summit–Landsburg Road, and Kent Kangley Road. These types of activities have resulted in some modifications to the stream channel (riprap and straightening) and localized loss of riparian trees.

## References

Hankin, D.G. and G.H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45: 834-844.

Jones and Stokes Associates, Inc. (Jones and Stokes). 1993. Wilderness Retreat/Wilderness 50 stream survey. Technical appendix. Prepared for the King County Dept. of Development and Environmental Services, Environmental Division, King County, WA.

King County. 1993. Cedar River Current and Future Conditions Report. King County Department of Public Works Surface Water Management Division. Seattle, Washington.

Martin, D. and L. Benda. 2000. Patterns of in-stream wood recruitment and transport at the watershed scale. Prepared by Martin Environmental, Seattle, Washington.

May, C.W. 1998. The cumulative effects of urbanization on small streams in the Puget Sound lowland ecoregion. Puget Sound Water Quality Action Team, Seattle, Washington. http://www.wa.gov/puget_sound/98_proceedigns/pdfs/1a_may.pdf

McCain, M., D. Fuller, L. Decker and K. Overton. 1990. Stream habitat classification and inventory procedures for northern California. (R-5's Fish habitat relationships Technical Bulletin number one). U.S. Forest Service. Arcata, CA. As cited in Jones and Stokes 1993

Montgomery, D.R., and J.M. Buffington. 1993. Channel Classification, Prediction of Channel Response, and Assessment of Channel Condition. Report TFW-SH10-93-002 to the SHAMW Committee of the Washington State Timber/Fish/Wildlife Agreement. Washington Department of Natural Resources, Olympia Washington.

MCS Environmental, Inc. (MCS). 2003. Rock Creek 2002-2003 salmonid spawning survey Kent, Washington. Prepared for the City of Kent. 8 p. plus appendices.

Pentec Environmental. 2001. Rock Creek Fish Habitat Surveys. Memorandum to T. Mortimer, Counsel for the City of Kent.

Priest, B. and H. Berge. 2002. 2001 salmon spawning surveys in selected tributaries of the Cedar River, Washington. King County Dept. of Natural Resources and Parks.

R2 Resource Consultants, Inc. (R2). 2004a. Biological monitoring of Rock Creek, Washington. 2003-2004 salmonid spawning surveys. Prepared for the City of Kent, Washington.

R2 Resource Consultants, Inc. (R2). 2004b. Unpublished Rock Creek habitat survey data. Prepared for the City of Kent, Washington.

Washington State Forest Practices Board (WFPB). 1997. Standard Methodology for Conducting Watershed Analysis under Chapter 222-22 WAC, Version 4.0. Timber/Fish/Wildlife Agreement and WFPB, Olympia.

Williams, R.W., R.M. Laramie and J.J. Ames. 1975. A catalog of Washington streams and salmon utilization, volume 1, Puget Sound region. Washington Dept. of Fisheries.

*This page intentionally left blank.*

# APPENDIX C

## The Hydrogeology of Rock Creek

*This page intentionally left blank.*

# Appendix C

## The Hydrogeology of Rock Creek
May 1, 2003

**The City of Kent was working to complete a Biological Assessment (BA) for its Clarks Springs Operations and this study was to be an Appendix to the BA. However after consideration, the City decided not to conduct a BA but instead to proceed directly with drafting the Habitat Conservation Plan.**

# *The Hydrogeology of Rock Creek*
# *Kent, Washington*

*Prepared for the*
*City of Kent, Engineering Department*

*by*
*Hart Crowser as*
*Appendix E of the*
*Clark Springs Biological Assessment*

*May 1, 2003*
*7470-06*

HARTCROWSER
Delivering smarter solutions

www.hartcrowser.com

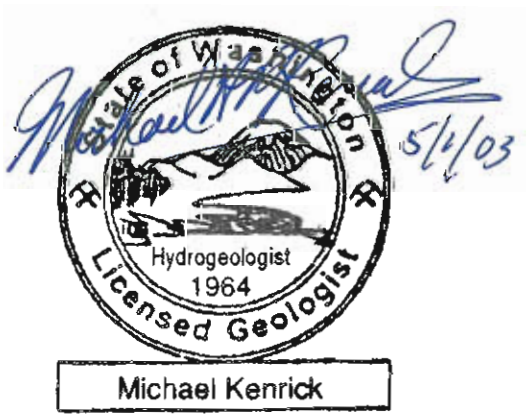
# The Hydrogeology of Rock Creek
# Kent, Washington

**Prepared for the**
**City of Kent, Engineering Department**

**by**
**Hart Crowser as**
**Appendix E of the**
**Clark Springs Biological Assessment**

**May 1, 2003**
**7470-06**

Prepared by
**Hart Crowser, Inc.**




Michael A.P. Kenrick
Principal

Anchorage
Boston
Denver
Edmonds
Jersey City
Long Beach
Portland
Seattle

1910 Fairview Avenue East
Seattle, Washington 98102-3699
Fax 206.328.5581
Tel 206.324.9530

CONTENTS

Page

1.0 EXECUTIVE SUMMARY 1

2.0 INTRODUCTION 3

*2.1 Purpose and Scope* 3
*2.2 Previous Investigations* 4
*2.3 Current Investigations* 7

3.0 DESCRIPTION OF THE ROCK CREEK CATCHMENT 8

*3.1 Location and Setting* 8
*3.2 Geology* 15
*3.3 Hydrology* 21
*3.4 Hydrogeology* 35

4.0 SURFACE WATER AND GROUNDWATER INTERACTION 45

*4.1 Upper Rock Creek Valley Plain* 46
*4.2 Rock Creek at Clark Springs* 46
*4.3 Lower Rock Creek — Perennial Stream* 61

5.0 MANAGEMENT STRATEGIES 62

*5.1 Watershed Controls* 62
*5.2 Clark Springs Operations* 63
*5.3 Streamflow Augmentation* 63

6.0 CONCLUSIONS 65

7.0 REFERENCES 67

TABLES

1 Manual Streamflow Measurements
2 DOH Well-Based Water Systems in Rock Creek Basin
3 Water Rights in Rock Creek Basin
4 Water Production History at Clark Springs

## FIGURES

1 Vicinity Map, Rock Creek Catchment
2 Drainage Basin Map, Rock Creek Catchment
3 Variation in Mean Monthly Precipitation
4 Distribution of Mean Annual Precipitation, Rock Creek Catchment
5 Conceptual Regional Geologic Cross Section, Rock Creek Catchment
6 Detailed Geology Map, Rock Creek Catchment
7 Glacial Retreat in Southeastern Puget Sound
8 Detailed Geology Map, Lower Rock Creek Catchment
9 Generalized Geologic Cross Section A-A', Lower Rock Creek
10 Generalized Geologic Cross Section B-B', Lower Rock Creek
11 Generalized Geologic Cross Section C-C', Lower Rock Creek
12 Generalized Geologic Cross Section D-D', Lower Rock Creek
13 Hydrology Map, Rock Creek Catchment
14 Rock Creek Streamflow Data
15 Streamflow Analysis, Rock Creek Catchment
16 7-day Low-Flow Analysis, Rock Creek Catchment
17 1999 Land Use Map, Rock Creek Catchment
18 Hydrogeology Map, Rock Creek Catchment
19 Ravensdale Well Hydrograph and Volume Pumped
20 Hydrographs of Monitoring Well, City of Kent Wellhead Protection Area
21 Site and Facility Map, Clark Springs
22 Water Production from Clark Springs
23 Interpreted Baseflow of Lower Rock Creek
24 Clark Springs Infiltration Gallery Test
25 Distance-Drawdown Relationship, Clark Springs Infiltration Gallery Test
26 Infiltration Gallery System Test
27 Clark Springs Wells, Pumping Test - December 1997

# THE HYDROGEOLOGY OF ROCK CREEK
# KENT, WASHINGTON

## 1.0 EXECUTIVE SUMMARY

This technical report provides a detailed presentation and analysis of a wide range of new and existing data relating to the Hydrogeology of Rock Creek. The study area is the Rock Creek surface water catchment, which lies within the eastern portion of the Covington Uplands in southeastern King County, Washington, and forms the largest tributary to the Cedar River. The analysis has been prepared to support the City of Kent's Biological Assessment (BA) of Clark Springs Water Supply System (CSWSS), which is located in the catchment. We specifically address the factors that control the amount of water available for supply system withdrawals and to maintain streamflow in the lower reaches of Rock Creek.

The report provides descriptions of how the groundwater system within the Rock Creek catchment operates as the primary source of baseflow to the creek. The extensive plain upstream of Ravensdale contains a shallow unconfined aquifer within highly transmissive glacial deposits that constitutes the main source of water in the system. However, a portion of water from the upper catchment does not reach Clark Springs but leaves the Rock Creek system as groundwater flow down one or more aquifer channels (e.g., at Ravensdale) upstream of Clark Springs. These groundwater losses reduce the amount of flow available at Clark Springs and in the lower reaches of Rock Creek.

Baseflow discharge from the aquifer at Clark Springs sustains surface water flows within the lower reaches, but varies seasonally as a function of fundamental components of the hydrologic cycle, such as groundwater recharge that is derived from temporally variable amounts of precipitation.

A historical analysis of streamflow measurements from the last 50 years is used to show that gains or losses to streamflow in the lower reaches are negligible, downstream of Clark Springs. The analysis also shows that there is evidence for a systematic reduction of streamflows and basin yields in the past. A reduction of flows on the order of 6 cfs coincides approximately with the start of CSWSS operations but the cause and effect are confounded by the existence of a drainage diversion into the Green River that removed a similar amount of streamflow out of the Rock Creek system from at least the early 1960s, through until 1997 (when the diversion was closed by King County). Currently, there is insufficient data to show whether streamflows and basin yields have recovered to pre-1960s levels.

The interaction between the surface water and groundwater in Rock Creek is complex and varies in time and space, reflecting different hydrogeologic conditions along the course of the creek, as well as transient variations in precipitation and groundwater storage. Using field data, existing reports, streamflow measurements, and reviews geologic maps, etc., we have developed a conceptual model of the catchment that provides an improved understanding of the interactions between groundwater and streamflow, as well as other factors that control water availability. The conceptual model forms the basis for numerical modeling of the Rock Creek catchment that is being conducted for the Clark Springs BA.

The conceptual model provided the basis for an HSPF surface water model and a ModFlow groundwater flow model, both of which are described in separate appendices to the Clark Springs BA. These models simulated the complex interactions and hydrologic processes that control the generation of streamflow in the creek under a range of natural conditions. The report then examines how these flows are affected by CSWSS operations, which include an infiltration gallery, three deep wells, and a pumping system that provides streamflow augmentation by drawing on groundwater during periods of low in-stream flow.

The results from two detailed system tests conducted on the CSWSS facility focus on the surface water/groundwater interaction that controls flows near the City's withdrawal facilities. These tests show that the sources of water extracted by the CSWSS facilities are principally from groundwater, but that the main effect of the system is to capture baseflow that would otherwise discharge to the creek.

An important secondary effect observed during monitored tests on the CSWSS is the removal of water from storage within the aquifer rather than directly from flow in the stream. This becomes significant at periods of low in-stream flow, when declining groundwater levels cause the water table to drop below the level of the creek, and baseflow capture becomes a less significant component. It is this mechanism that allows the CSWSS to operate during periods of low flow, with a smaller amount of streamflow depletion occurring, than may otherwise be expected.

The hydrogeologic conditions pertaining during low-flow also appear to enhance the benefits of streamflow augmentation by diverting a portion of groundwater flow into the stream – groundwater flow that would otherwise leave the catchment. The relative absence of significant losses in the perennial downstream reaches, even during critical late summer periods, ensures that these added flows largely remain in Rock Creek until the confluence with the Cedar River.

## 2.0 INTRODUCTION

The hydrogeology of Rock Creek is being investigated for the City of Kent (City) as one element of the Clark Springs Biological Assessment (BA). Hydrology and geology comprise the primary physical characteristics that control streamflow in the Rock Creek catchment. A better understanding of these characteristics will help to determine potential impacts of the City's Clark Springs Water Supply System (CSWSS) operations on flows in Rock Creek.

Based on previous work in the area, the hydrologic relationships between groundwater and surface water within the Rock Creek catchment are of fundamental importance in understanding the hydrology of the creek and determining the potential effects that water withdrawals and other developmental changes throughout the catchment may have on streamflow in the creek. A portion of streamflow appears to be derived from groundwater discharge from the extensive shallow aquifer that occupies the upper portion of the Rock Creek catchment. Groundwater enters the creek as baseflow primarily above and within the Clark Springs Watershed; flow in the creek is perennial downstream of the watershed. The City withdraws water from the CSWSS facilities at Clark Springs to meet a significant part of the water demand in the area served by the City's water supply network.

The following subsections summarize the purpose and scope of the work performed for this project, list the reports documenting published results of previous investigations relating to the hydrogeology of Rock Creek that have been used to help develop the understanding presented in this report, and provide an overview of current investigations performed to support the findings and conclusions of this study.

### *2.1 Purpose and Scope*

The main purpose of this study was to develop an understanding of the relationships between groundwater and surface water throughout the Rock Creek system, and in particular to examine the interaction between Rock Creek and the shallow groundwater system within the catchment. An improved understanding of the surface water and groundwater hydrology of the Rock Creek catchment will shed light on the factors that that influence surface water flows and conditions within the perennial lower reach of Rock Creek. Knowledge of those factors potentially relate to CSWSS operations will be used in the development of a BA and HCP to assist the City in managing water resources.

Significant hydrogeologic objectives of the Clark Springs BA include:

- Showing that the water resources sustaining Rock Creek and the CSWSS facility are derived primarily from groundwater recharge occurring in an extensive catchment extending upgradient from Ravensdale to Lake Twelve;

- Quantifying the degree to which water withdrawals from CSWSS facilities may affect flows in the perennial reach of Rock Creek downstream;

- Establishing the magnitude of streamflow gains or losses (to groundwater) that occur in the perennial reach downstream of Clark Springs;

- Examining how the range of streamflows observed in Rock Creek during recent years may have been impacted by other key factors affecting the hydrology of the upper catchment;

- Establishing the extent to which development and other land use changes in the Rock Creek catchment may have affected or will effect the availability of water resources for Clark Springs and the perennial downstream reach;

- Assessing the effectiveness of streamflow augmentation to mitigate low flows conditions downstream of Clark Springs; and

- Demonstrating that withdrawals at Clark Springs have no effect on the availability of water resources within the upper catchment of Rock Creek, upgradient of the CSWSS facilities.

This report presents the background information and field data collected to support the findings and conclusions made regarding these hydrogeologic objectives.

## *2.2 Previous Investigations*

Numerous geologic and hydrogeologic investigations have been conducted previously in south King County and the greater Cedar River watershed area that have some bearing on the hydrogeology of Rock Creek. Brief summaries of the applicable investigations reviewed in the course of this study are presented below:

- Hart Crowser (1996) prepared a Wellhead Protection Program for the City of Kent's Clark, Kent, and Armstrong Springs facilities. The Wellhead Protection Program (WHPP) is designed to protect groundwater resources supplying public sources of drinking water within the Covington Uplands. The WHPP consists of delineation of the wellhead protection area, identifies potential contaminant sources, and presents management strategies along

with a monitoring plan, spill response plan, and a water supply contingency plan. In developing the Program, the report presents significant background on the geology and hydrogeology of the Covington Upland and the adjacent Cedar River Basin. This information was used in the development of our conceptual model of the Rock Creek catchment.

- Robinson & Noble, Inc. (1995) concurrently prepared a Wellhead Protection Plan for the Covington Water District. This Wellhead Protection Plan covered the 222nd Street Wellfield, located southeast of the CSWSS facilities, downstream of Ravensdale Lake and the southern discharge channel of the Rock Creek Basin. The program addressed three primary areas of interest: wellhead protection area delineation, existing and potential contamination hazard identification, and protection strategies and implementation tasks. The report presents detailed background on the geology and hydrogeology of the area, which was used in development of the conceptual model presented in this report.

- A Hydrology Evaluation for the Boundary Line Adjustment, Ravensdale, Washington, was reported by GeoEngineers (2000) for Jack McCann Company. The evaluation was intended to establish boundaries for 57 residential building lots distributed over 125 acres between Ravensdale and the Clark Springs Watershed. The evaluation concluded that sufficient vertical separation is maintained throughout the project site between seasonal high groundwater level and surface grade elevations to allow for on-site septic systems. The analysis uses the 100-year, 7-day precipitation event to establish groundwater elevations and to assess the potential for groundwater quality impacts from stormwater infiltration, development land use, and septic effluent. The report also assesses the effect of development on a tributary to Rock Creek. Pertinent information contained in the report included logs and water level records for monitoring wells drilled around the site and streamflow measurements taken during a storm event in January 2000.

- A Draft Environmental Impact Statement (King County 1987) prepared for the Kangley Site Sand and Gravel Operation located in the northeast corner of the Rock Creek catchment, just north of Kent-Kangley Road. The purpose of the document is to discuss a request to rezone 610 acres of Forest-Recreation zoned land to Quarry-Mining. As part of the discussion, a detailed description of the geology and hydrogeology of the area is presented. In particular, the lateral and vertical extents of the gravel deposits and their potential yield were described, as well as the bedrock groundwater divide existing in the northeast portion of the site. This bedrock divide is

significant in understanding and quantifying the groundwater regime within the Rock Creek catchment.

- Geologic maps used in researching and developing the conceptual model of the Rock Creek catchment hydrogeology include:

  - Geologic Map of Southwestern King County, Washington, by J. E. Luzier of Department of Water Resources, State of Washington (1969);

  - Geology and Coal Resources of Central King County, Washington, by Timothy J. Walsh of Department of Natural Resources, State of Washington (1984); and

  - Currently unpublished geologic studies by Bill Lingley, of the Washington State Department of Natural Resources (DNR), who is researching and mapping the occurrence of thicker deposits of potential sand and gravel resources in the region.

Other studies relating to the hydrogeology of Rock Creek include:

- A Groundwater Management Plan (GWMP) for South King County (1991), prepared under grants from the Washington State Department of Ecology (Ecology). Supervised by the South King County Groundwater Advisory Committee, the general program goal of the reports was to "establish and implement groundwater management procedures and functional responsibilities that will protect existing water resources and prevent the future degradation of water quality or inefficient utilization of groundwater resources."

  The GWMP presents conclusions and recommendations on the principal aquifers and management practices in the Covington Upland that extends to Clark Springs. It lists basic information about the City's water supply facilities located in this area. The report also describes the regional hydrogeology; presents an approximate regional recharge estimate (21.6 inches/year), based on a water balance between precipitation, runoff, and evapotranspiration; and calculates a hypothetical groundwater yield of the aquifers in the area.

- A Current and Future Conditions Report for the Cedar River, prepared by the King County Department of Public Works, Surface Water Management Division (1993). The document provides an assessment of the current conditions and predicts future trends in the Cedar River Basin Planning Area. The primary purpose is to identify significant conditions and issues to be

addressed in recommended solutions and management programs for problems related to flooding, erosion and deposition, water quality, and aquatic habitat. The report provides general background to the geology and a qualitative assessment of groundwater in the basin. Information in this report provides useful background and includes details of the first HSPF modeling of the Rock Creek catchment, but lacks the detail required for the present study.

Relevant information contained in these various reports has been collated and synthesized together with field evaluations, observations, and analyses of historical and current data performed under this study to develop a comprehensive picture of the hydrogeology of the Rock Creek catchment.

## 2.3 Current Investigations

The current investigations performed for this report in support of the Clark Springs BA included the following tasks:

- Data research and review of published reports;
- Research and preparation of detailed land use maps;
- Verification of the catchment boundary from detailed mapping;
- Field mapping and reconnaissance of the Rock Creek stream channel;
- Research, evaluation, and collation of existing geologic mapping studies;
- Development of the conceptual hydrogeologic catchment model;
- Review of existing private water supply systems;
- Review of existing water wells per Ecology records;
- Collation and review of streamflow records from USGS;
- Critical analysis of streamflow data collected by King County;
- Compilation and analysis of manual streamflow measurements;
- Field investigation and flow testing at Clark Springs;
- Development of input data for the Modflow modeling task; and
- Installation of streambed piezometers at selected locations.

The results of these investigations were analyzed in the context of and integrated with other technical tasks performed for the Clark Springs BA, including:

- Hydrologic Analysis using the HSPF Model (Appendix C);
- The Geomorphic Study (Appendix D); and
- The Rock Creek Catchment Groundwater Flow Model (Appendix F).

A large amount of information has been collected, reviewed, and analyzed to develop the findings presented in this report and in the companion reports comprising the listed appendices. The technical areas covered by each report

overlap to some extent but we have limited repetition of information that is contained in these or other appendices.

# 3.0 DESCRIPTION OF THE ROCK CREEK CATCHMENT

This section provides a detailed description of the Rock Creek catchment that covers location and setting; geology; hydrology; and hydrogeology. The information presented here is fundamental to a clear understanding of the complex interrelationships that govern the flow of water both in Rock Creek and in the underlying aquifer that supplies water to Clark Springs. The information also provides the conceptual framework for the development of computer models to simulate the surface flows in Rock Creek and groundwater flows in the aquifer, as presented in Appendix C and Appendix F, respectively, of the Clark Springs BA.

## *3.1 Location and Setting*

The Rock Creek catchment is located southeast of Maple Valley, Washington, on the eastern part of the Covington Uplands. The location is in the southeastern portion of the Puget Sound lowland where it merges into the glaciated foothills of the Cascade Range (Figure 1). The catchment lies between the Cedar River to the north, and the Green River to the south. The mouth of Rock Creek is located at latitude 47° 22' 54" N and longitude 122 °01' 00" W in Township 22 Range 23 Section 6, and forms the largest tributary of the Cedar River where it enters on the left bank at River Mile (RM)18.15.

The CSWSS facilities are located on Rock Creek approximately 1.7 miles upstream from the confluence with the Cedar River (i.e., RM 1.7), as shown on Figure 2. The facilities are located within City of Kent property known as the Clark Springs Watershed, which has an area of 330 acres. The property straddles the Kent-Kangley Road east of Summit and southeast of Maple Valley.

### 3.1.1 Demographics

There are a number of small towns and villages within or on the periphery of the Rock Creek catchment (Figure 2). These include:

- Summit (Four Corners), located west of the catchment, around the intersection of Kent-Kangley Road and the Maple Valley Highway;
- Landsburg, the location of the City of Seattle's water supply off-take from the Cedar River, just north of the catchment boundary;

- Ravensdale, which now forms two adjacent built-up areas located 3 miles east of Summit, on Kent-Kangley Road; one of these areas at Landsburg Road encompasses the village previously known as Georgetown;

- Evergreen Acres, a residential subdivision, located 3 miles east of Ravensdale;

- Kangley, located just beyond the eastern boundary of the catchment; and

- Palmer, located just beyond the southeastern boundary.

There are also residential developments around the two main lakes within the catchment, Retreat Lake and Lake Twelve (Figure 2). The larger towns of Maple Valley and Black Diamond are located northwest and southwest of the drainage basin, respectively. A portion of Maple Valley containing some residential subdivisions and commercial developments located to the west of the Rock Creek Natural Resource Area, extends into the western part of the Rock Creek catchment boundary (Figure 2).

The remainder of the upper catchment is characterized by dispersed rural development comprising homesteads, pastureland, and hobby farms on the valley floor. Upland hillslopes tend to be forested or have been harvested for timber.

### 3.1.2 Topography

The valley floor of the upper Rock Creek catchment forms a plain that is bounded by bedrock hills. Elevations of these hills approach 1,000 feet above mean sea level (MSL), while the valley of the upper catchment is around 570 feet MSL at Clark Springs, rising to 750 feet at the foot of Sugarloaf Mountain (Figure 2). Several till-covered knobs are present within the upper catchment, together with the occasional depressions that contain wetlands or small lakes.

Downstream of the Clark Springs Watershed, Rock Creek descends the southern wall of the Cedar River valley and enters the alluvial floodplain of the Cedar River at an elevation of around 425 feet MSL. The confluence of Rock Creek with the Cedar River is at an elevation of 405 feet MSL.

For this study, the Rock Creek catchment has been defined by surface topography, following the precedent set by King County in the development of its Cedar River Conditions Report (King County 1993 — see Map 28 of that report). Detailed topographic mapping of the catchment performed by Triathlon

under contact to the City has allowed us to determine an accurate boundary for most of the catchment, as discussed in Section 3.1.4.

### 3.1.3 Climate and Weather Data

The temperate climate of the Puget Sound Lowland, exemplified by generally mild temperatures with wet winters and dry summers, extends into the project area. Recently there have been some notably dry years (e.g., 2001), with rainfall substantially below normal. Climatic trends as projected by NOAA and USGS suggest that milder winters may be expected in the future, with less snowpack, and potentially less recharge than in past years.

#### *Precipitation*

Precipitation is characterized by sustained periods of moderate or low intensity rainfall in the fall, winter, and spring, with low to moderate snow accumulation for short periods during colder weather. Ground freezing is relatively uncommon or short-lived.

Data on precipitation are available from three weather stations in the region:

- Landsburg, mean annual precipitation of 56.5 inches;
- Buckley (near Black Diamond), mean annual precipitation of 48.8 inches; and
- Palmer, mean annual precipitation of 90.1 inches.

The variation in mean monthly precipitation at these three stations since 1932 is summarized on Figure 3.

The analysis of precipitation in the Rock Creek catchment used by King County in its first attempts to simulate basin yield (King County 1993) used data from Seattle and Landsburg stations, but erroneously factored the average precipitation downward to develop a mean annual precipitation estimate for the Rock Creek catchment of around 46 inches per year. No explanation is given by King County for this assumption. We infer that lower rainfall inputs were adopted by King County to assist in the calibration of the early versions of its HSPF model, which critically failed to include significant out-of-basin groundwater flows that more correctly account for reduced basin yield. (For more details, see the HSPF modeling report in Appendix C of the Clark Springs BA.)

The low values of precipitation used by King County appear to ignore an increasing orographic effect from west to east across the Rock Creek catchment

that produces wetter conditions in the east (i.e., at Palmer), with mean annual precipitation exceeding 60 inches and increasing more rapidly over Sugarloaf Mountain. This effect is well-demonstrated in data from the PRISM studies (Oregon Climate Service 1997) utilized in Appendix C for the HSPF modeling task, which show mean annual precipitation increasing to the east across the Rock Creek catchment (Figure 4).

For modeling work in support of the Rock Creek BA, Hart Crowser's subconsultants, MGS Engineering Consultants Inc., developed the HSPF model of the Rock Creek catchment as presented in Appendix C of the Clark Springs BA. For this effort, MGS divided the catchment into two precipitation zones based on data from the PRISIM model. West of Ravensdale, a mean annual precipitation of 56.2 inches is applied; to the east of Ravensdale, a mean annual precipitation of 60.5 inches is applied. See Appendix C of the Clark Springs BA for more details on the analysis and application of precipitation data to the project.

### *Evaporation*

Evaporation data for the region are derived from the Western Washington Experiment Station at Puyallup (WRCC 2002). For the Clark Springs BA, these data are utilized in the HSPF modeling of catchment hydrology, as presented in Appendix C. Mean monthly values of pan evaporation (in inches) for the period of record from 1931-95 are:

| | | | |
|---|---|---|---|
| January | 0.00 | July | 5.61 |
| February | 0.71 | August | 4.97 |
| March | 1.58 | September | 2.92 |
| April | 2.46 | October | 1.28 |
| May | 3.97 | November | 0.61 |
| June | 4.63 | December | 0.00 |

The average annual pan evaporation is 28.74 inches.

## 3.1.4 Drainage Area

The boundary of the surface water drainage area for the Rock Creek catchment has been carefully reassessed as one of the tasks for the Clark Springs BA. This is critical for any resource assessment or modeling work that simulates catchment hydrology because the contributing topographic area determines the amount of precipitation that is calculated to enter the catchment and become available for streamflow and groundwater recharge.

The drainage area of a stream is conventionally defined by surface topography; the boundary is traced on a map as a ridgeline that separates surface runoff destined for adjacent streams (ignoring infiltration). This method of delineation works well in areas of moderate or high topographic relief, but can become problematic in flat areas, where elevation data do not have the accuracy or precision necessary to determine proper flow directions.

The issue is of some importance for any analysis of the Rock Creek catchment because the drainage area has been represented in a number of different realizations in the past – the results of previous determinations still remain in some key instances, as described below.

### *Water Resource Inventory Areas*

One of the more significant discrepancies in the documentation of drainage area for Rock Creek relates to the delineation of Water Resource Inventory Areas (WRIAs), as established by state legislation under the Water Resources Act of 1971 (RCW 90.54). The boundary between WRIA 8 (the Cedar River basin) and WRIA 9 (the Green River basin) passes through the northern part of the Rock Creek catchment, which is situated between these two rivers (Figure 1).

In maps published by Ecology (and currently available on their website - Ecology 2003), the boundary between WRIA 8 and WRIA 9 divides the Rock Creek catchment in the area of Ravensdale. The position of the WRIA boundary incorrectly implies that most of upper Rock Creek catchment east and southeast of Ravensdale drains to the Green River, not the Cedar River. On the basis of the WRIA boundary, the drainage area for Rock Creek would be only around 2,000 acres (3 square miles [$mi^2$]).

WRIA boundaries are subject to revision, but this error in delineation of the watersheds that make up the WRIAs does not appear to have been corrected at state level. However, various maps from King County that depict WRIAs draw the boundary so as to include the Rock Creek catchment completely within WRIA 8 (Cedar River), which is consistent with the re-evaluation we performed for the Clark Springs BA, based on more accurate topographic mapping data.

### *Catalog of Washington Streams*

Alternative sources of drainage area information include the *Catalog of Washington Streams*, prepared by Williams et al. (1975). Although not listed by name, the map location in the catalog identifies Rock Creek as Stream Number 0338 with a drainage area of approximately 12.6 $mi^2$. The quoted stream length

of 3.2 miles would actually encompass the tributary known locally as Georgetown Creek (see Figure 2).

Williams catalogues another stream (Number 0339) as a tributary of Rock Creek; this corresponds to the intermittent upper reach of Rock Creek (above the confluence with Georgetown Creek) that can be traced upstream to Lake Twelve.

Despite the work done by Williams et al. (1975) some studies published subsequently (e.g., Brown & Caldwell 1980) show the drainage area of the Rock Creek with a watershed boundary that split the upper catchment south of Retreat Lake, with the southern portion (including Lake Twelve) being placed in the Green River catchment. Better understanding of water flows along the full length of Rock Creek led to this boundary being revised in subsequent studies.

### *Cedar River Conditions Report*

A detailed study on the Cedar River system (King County 1993) identifies Rock Creek as the largest tributary to the Cedar River system with a stream length of 8.0 miles up to the outflow from Lake Twelve (Figure 2). The report cites the drainage area for Rock Creek variously as:

- 7,695 acres (12.02 $mi^2$) in Table 3-4 (page 3-23);
- 8,094 acres (12.65 $mi^2$) in Table 1 of the Hydrology Appendix (page 5);
- 8,397 acres (13.12 $mi^2$) in Table 2 of the Hydrology Appendix (page 11); and
- 11.1 $mi^2$ (7,104 acres on page 4-30).

The range of uncertainty conveyed by these figures is ±560 acres, or ±7 percent of the mean drainage area. For modeling purposes, King County divided the Rock Creek catchment into nine sub-basins (designated R1 through R9), but the drainage area calculations appear to inexplicably exclude subcatchment R9 (see Figure 2). If R9 were included, the total drainage area for Rock Creek based on the Conditions Report would be around 9,500 acres (14.8 $mi^2$).

### *Clark Springs BA*

For the Clark Springs BA, the City of Kent commissioned a topographic survey of the entire Rock Creek catchment area by Triathlon, with increased resolution that allowed mapping of ground surface elevation contours at 5-foot intervals -- a significant increase in accuracy over USGS 7½-minute quadrangle maps with 20-foot contour intervals. On the basis of the more detailed topographic relief and improved mapping scales possible with this new mapping coverage, we

have redrawn the catchment boundary with an increased degree of accuracy, as shown on Figure 2. The calculated drainage area is 10,035 acres (15.68 $mi^2$).

Most of the difference with previous drainage area estimates appears to be accounted for by the inclusion of sub-basin R9, which was left out of calculations and modeling in King County's Conditions Report (1993). There are also some differences in places where the drainage boundary we have drawn crosses areas of low topographic relief. These areas of uncertainty are mainly in the northeast, southeast, and northwest of the delineated catchment (Figure 2). The accuracy of the resulting drainage area is therefore estimated to be on the order of ±300 acres to allow for some uncertainty in the flat areas where boundary delineation is poorly defined. This represents an accuracy of ±3 percent.

For the purpose of this study, we have divided the Rock Creek catchment into three primary sub-basins—the upper Rock Creek catchment, Clark Springs Watershed, and the lower Rock Creek catchment, as shown on Figure 2. Creek flow at and below Clark Springs is perennial, whereas flow in the upper catchment is intermittent.

The upper part of the catchment occupies a broad triangular valley plain ringed by hills. The overall boundaries of the Rock Creek catchment are defined by surface topography as follows:

- The northern boundary of the upper catchment extends along a line of hills that run east-west, delineating the south side of the Cedar River valley;

- To the east, the catchment boundary generally runs north-south over Sugarloaf Mountain to include the Kent-Kangley sand and gravel pit in Section 27 (Figure 2);

- In the south, the Green River gorge forms an unusual boundary, with the river deeply incised into a narrow bedrock gorge to a depth of around 200 feet lower than the floor of Rock Creek valley; and

- In the west, the boundary is defined by the hills surrounding Lake Twelve and extending north along Ravensdale Ridge to the hill south of Clark Springs (locally called Maple Ridge).

Some of the boundaries are more accurately drawn across elevated ridgelines or hilltops, while in other areas of low topographic relief, the boundary is poorly defined, especially since there is little or no surface runoff, and the hydrologic function of some peripheral areas is such that they do not contribute any surface

water flow to Rock Creek. These marginal areas on the drainage area boundary are discussed further in Section 3.3.1.

## 3.2 Geology

The geology of the project area consists of consolidated Tertiary bedrock overlain by unconsolidated sediments deposited during the Quaternary period (the last 750,000 years). The Quaternary sediments deposited in the project area are mainly the result of the latest glacial advance and retreat of the Vashon Glacier, which ended around 15,000 years ago.

The low hills defining the upper Rock Creek catchment represent the first visible expression of bedrock as one moves eastward out of the Puget Sound Trough, where bedrock depths in places approach 5,000 feet. The hills immediately north and south of Clark Springs are composed mainly of bedrock whereas, to the west of Clark Springs, the bedrock surface falls away rapidly, to be overlain by an increasing thickness of glacial deposits that blanket much of the Puget Sound lowland. To the east, bedrock elevations increase into the Cascade Foothills, as shown on Figure 5, a schematic geologic cross section drawn through the area, looking north (after Luzier 1969).

### 3.2.1 Geologic History

The unique geologic history of the project area has played a significant role in shaping the catchment and creating the complex conditions described in this report. This sections presents a brief summary of the main geologic events and their influence on current conditions.

#### *Bedrock*

The Tertiary volcanic and sedimentary bedrock in the region dates from the Eocene to the Oligocene series, between 24 and 37 million years old. The bedrock has been regionally folded as part of the Newcastle Hills anticline. The Rock Creek catchment is located on the southwest limb of the fold. The sedimentary bedrock in the area has been actively mined for coal, such as the John Henry Mine located west of Lake Twelve, and the Landsburg Mine located northeast of Clark Springs. The bedrock provides the underlying structure over which subsequent glacial action and deposition of unconsolidated sediments occurred. The general distribution of these sediments and the outcrops of bedrock are mapped for the Rock Creek catchment area on Figure 6.

### *Quaternary Glaciation*

Episodes of glaciation in the Puget Sound Lowland area began around 750,000 years ago, with glaciers up to 5,000 feet thick gouging out the bedrock beneath Puget Sound. Repeated glacial advances and recessions over the period of the Ice Ages alternately deposited and then compressed massive amounts of glacially derived sediment over the bedrock in the central area of Puget Sound. Rock Creek catchment is located near the southeastern limit of the most recent glacial advance, as shown on Figure 7.

### *Vashon Stade*

The topography of the Rock Creek catchment results mainly from the Vashon stade, which formed the last episode of the Fraser glaciation, when the Vashon Glacier advanced into the Puget Sound region from the north. While advancing southward, the meltwater from the glacier deposited coarse-grained sand and gravel in a formation now characterized as Advance Outwash.

As the glacier proceeded further south, subglacial till was deposited below the glacier, on top of the advance outwash. A pro-glacial lake was formed in front of the advancing glacier, blocking north flowing drainages. Drainage was re-established to the south in front of the advancing glacier. Sand would commonly give way to gravel because of the increased gradient adjacent to the approaching glacier; therefore, stratifying the advanced outwash from finer to coarse sediment. Sediments from these pro-glacial lakes are generally undifferentiated within the study area.

### *Glacial Retreat*

At its furthest extent, the Puget Sound lobe of the Vashon glacier extended to the ridge east of Sugarloaf Mountain, occupying the upper Rock Creek catchment and spreading further up the ancestral Cedar River and Green River valleys to the north and south (see Figure 7). As the Puget Sound lobe receded from the upper Rock Creek catchment, ice-contact deposits were deposited along the margin of the retreating, or isolated portions of the glacier. These deposits, which are also known as kame terraces, remain in the central portion of the upper catchment and generally consist of mixed materials deposited in an uneven or hummock terrain with numerous depressions and kettle holes.

### *Glacial Outwash Channels*

At stages during the glacial recession, repeated surges of glacial meltwater and runoff flowing around the edge of the ice lobe from the northeast coursed

through the project area, creating large outwash channels on either side of Sugarloaf Mountain that appear to have scoured out ice-contact deposits, leaving broad flat areas underlain by coarse, highly permeable outwash deposits (Figure 6).

During a subsequent stage in the recession of the Puget Sound lobe, the ice margin was located for a time in the Cedar River valley, with the mass of ice extending north and west, into Puget Sound. This massive ice blockage forced meltwater from the regional glaciers, combined with runoff from the Cascades, to flow down a marginal river channel approximately following the foothills of the Cascades, with flow from northeast to southwest. This marginal channel extended through Grouse Ridge and Cedar Falls to the northeast of Rock Creek (see Figure 7) through the Rock Creek Catchment and Covington Upland, eventually discharging into the swollen Puget Sound near Auburn in the southwest.

The resulting complex of meltwater channels and ice-dammed lakes deposited vast quantities of coarse-grained recessional outwash materials along its path, including the outwash that forms the floor of the upper Rock Creek valley plain. Multiple surges of meltwater likely scoured out the large outwash channel that runs across the northern part of the plain in a repeated series of events, redepositing or carrying additional sediment to the area (Figure 7). The recessional deposits thus comprise the majority of the aquifer underlying the northern valley plain, with vestigial signs of broad outwash channels still visible in the surface morphology of the current landforms.

### *River Incision*

Once glaciers retreated from the lowlands, restoring northward-flowing drainages and flow from Puget Sound into the Pacific, Puget Sound water levels dropped. This drop increased the river gradient and enabled the Cedar River and the Green River to entrench into their current deeply incised valleys, the difference being that the Green cut down through bedrock, whereas the Cedar cut down through older glacial deposits that were not as strong as the bedrock.

In the Cedar River valley, this downcutting exposed older sediments well below the elevation of the large outwash channel that can now be seen north of the Kent-Kangley gravel pit. Subsequent maturation of the Cedar River after entrenchment allowed for deposition of alluvium along the riverbank to form the current floodplain within the incised valley in the area of the confluence with Rock Creek.

Later, topsoil and peat have accumulated in places on the glacially deposited sediments. Peat is primarily associated with depressional wetlands and fully to partially saturated soils associated with perennial Rock Creek, marshes, and lake bottoms.

### 3.2.2 Stratigraphic Units

Characteristics of major stratigraphic units in the study area are described in this section, starting with the bedrock generally working upward toward the ground surface. Descriptions of these major units are adapted from Luzier (1969), King County (1993), and Robinson & Noble (1995) unless otherwise noted. Their relative locations, outcrops, and lateral extents of the various units within the project area are indicated on Figure 6, using their geologic abbreviations.

#### *Tertiary Bedrock (Tbr)*

The majority of the Tertiary bedrock belongs to the Puget Group with the exception of intrusive and volcanic rocks. The Puget Group consists primarily of sandstones and siltstones with occasional coal seams. Bedrock in the Rock Creek catchment is present primarily within the hills surrounding the catchment and underlies the valley floor at depths of 75 to 150 feet. The bedrock largely defines the overall shape of the catchment and its higher elevations provide the hydrologic boundaries, as described previously.

Bedrock outcrops are also present in the northeast valley floor, west of the Kent-Kangley gravel pit (Figure 6). Previous investigations suggest that the outcrops are part of a bedrock ridge extending northwest between the Kangley site and Evergreen Acres (King County 1987). The bedrock ridge has been almost completely buried beneath glacial sediment, but appears to act as an effective groundwater divide that is not associated with overlying surface topography. The implications of this bedrock divide on the groundwater hydrology of the upper catchment are discussed in Section 3.4.2 and in Appendix F (Section 2.2).

#### *Pre-Fraser Older Sediments (Qos)*

Older glacial sediments are exposed in places along the Cedar River and underlie much of the western portion of the Covington Upland outside of the project area. The pre-Fraser sediments were exposed by the down-cutting of the Cedar River after the regional glacier retreated from the Puget Sound lowlands. Alluvium was deposited along the flanks of the Cedar River by the meandering and episodic floods of the river channel.

To the west of Rock Creek, coarse- and fine-grained units alternate above the bedrock and below the Vashon-deposited sediments. These units are often mapped as undifferentiated pre-Vashon glacial drift deposits (Qu) or older sediments (Qos), arising from earlier glaciations of the Puget Sound region. Together, these sediments can be up to 1,000 feet thick, with the outwash layers having relatively good water yielding properties, but they are thought to underlie only the westernmost portion of the Clark Springs BA project area. These deposits may occur within the southern valley wall of the Cedar River valley, corresponding to their presence in the north wall (see Figure 6), but are largely obscured by thick deposits of recessional outwash in the lower Rock Creek catchment.

### *Vashon Advance Outwash (Qvr)*

Meltwater from the advancing glacier deposited predominantly sand, with some layers of pebble- to cobble-sized gravel. These permeable sediments appear to be relatively thin in the project area and do not play a significant role in the shallow groundwater utilized in the Rock Creek catchment. The only mapped exposure of advanced outwash in the catchment is along Rock Creek, near the confluence of the Cedar River where the creek has down-cut through the overlying recessional sediment. However, our field mapping suggests this exposure may be older pre-Fraser sediments (Qos) as described above.

### *Vashon Till (Qvt)*

Vashon Till is widespread throughout the study area. Till mantles most on the bedrock uplands and is present in isolated area within the catchment. The interior deposits are often associated with ice-contact deposits described below.

The Vashon Till is comprised of a heavily compacted mixture of gravel in a gray, clayey, silty sand matrix. The low permeability of the sediment often gives rises to perching conditions; the mantle of till overlying the bedrock hills in the upper catchment limits infiltration but encourages runoff and interflow.

### *Vashon Ice-Contact Deposits (Qvi)*

Ice-contact deposits reside in the central portion of the upper Rock Creek catchment, beneath Retreat Lake and expanding in a broad swath to the south (Figure 6). The sediments are silty sand and pebble- to cobble-sized gravel generally deposited as kames or kames terraces. The structures originate from sediment deposited in stream channels between the valley side and the lateral edge of the stagnant glacial ice. As the supportive ice melts away, the interior edge of the drift collapses to leave a hummocky surface often dimpled by kettle

holes (Ritter et al. 1995). This could explain the occurrence of Retreat Lake and other irregular surface features in the southcentral portion of the upper catchment.

### *Vashon Recessional Outwash (Qvr)*

Recessional Outwash comprises the majority of the shallow aquifer system in the Rock Creek catchment. The typically coarse sediments consist of well sorted, stratified sand or sand and gravel deposited in an ice-marginal river by the meltwater of the wasting lobe of the Vashon glacier. The Qvr occurs as the upper layer forming the surface of the outwash plain over much of the Rock Creek catchment with local areas of terrace and valley-train deposits in the easternmost part of the upper catchment. Recessional outwash also blankets most of the lower Rock Creek area (Figure 8).

### *Peat (Qlp)*

Peat and swamp deposits are present locally throughout the upper Rock Creek catchment. The deposits are usually fine-grained and highly saturated sediment associated intermittent surface water bodies. These water bodies include the perennial path of Rock Creek, Lake Twelve, Hidden lake, Crow Marsh, and other unnamed depressional water features scattered around the upper catchment.

### *Alluvium (Qal)*

Alluvium has been deposited along the flanks of the Cedar River by the meandering and episodic floods of the mainstream channel. Rock Creek traverses alluvium of the Cedar River floodplain in its lowest reaches (Figure 8). There is very little alluvial deposition associated with the Rock Creek channel above the floodplain, probably because the creek is characterized by continuing channel incisions, as noted in the Geomorphic Study conducted for this project (see Appendix D of the Clark Springs BA).

## 3.2.3 Geology of the Clark Springs Area

Particular attention has been paid in this study to developing an understanding of the geologic setting for the lower reach of Rock Creek, downstream from Clark Springs. The geologic map that covers this part of the project area is presented on Figure 8. As part of this work, cross sections have been developed through the study area, based on available mapping data, well log, field reconnaissance, and discussions with Dr. Bill Lingley of the Washington State Department of Natural Resources (DNR). The cross sections (Figures 9 through

12) depict the overall geologic structure, with identification and, where possible, correlation of water-bearing horizons.

This work was developed to aid understanding of the groundwater régime in the lower catchment, and how it may affect streamflows through the creation of either gaining or losing reaches. However, our mapping work, that included the installation of piezometers into the bed of the creek, has revealed a general absence of tributaries, springs and seeps, or seepage pressures feeding flow into the lower reach of Rock Creek, suggesting that groundwater does not play a significant role in adding to flows downstream of Clark Springs. This conclusion is corroborated by our extensive research and analysis of streamflow data, as presented below in Section 3.3.3.

## *3.3 Hydrology*

This section provides a detailed review and analysis of the hydrologic conditions and streamflow data that are available for Rock Creek together with data collected during this study. The analysis and interpretation of these data illustrate how the catchment functions hydrologically and reveal important information about the role that groundwater plays in maintaining streamflow of Rock Creek, especially during the summer months.

### 3.3.1 Surface Drainage

Although the catchment boundaries for Rock Creek have been defined by the fate of surface runoff or overland flow, these conditions occur quite rarely for much of the catchment, in which the dominant hydrologic processes are infiltration and groundwater recharge. In this section, we describe how each part of the catchment functions hydrologically, taking consideration of both surface flow and infiltration.

#### *The Upper Rock Creek Valley Plain*

Rock Creek is the principal water course of the upper catchment that extends from Clark Springs eastward through Ravensdale to Kangley and south to the edge of the Green River gorge. The apparent source of surface flow in Rock Creek is Lake Twelve (although, as we show later, the surface flows from Lake Twelve are generally lost to groundwater before the creek reaches Clark Springs).

Lake Twelve is located in the southwest corner of the catchment, and collects runoff from a subcatchment (designated R8 on Figure 13) formed by the surrounding hills, the lower portions of which are mantled with till (Figure 6). For

most of the year, water flows to the east from the lake outlet at RM 8.2, through a broad flat wetland complex known locally as Crow Marsh (Figure 13). Flow through the wetland is augmented by additional surface drainage from the hills to the north via an intermittent channel, which is known locally as Upper Rock Creek.

Surface flows from Lake Twelve discharge from Crow Marsh through a culvert beneath 290th Avenue SE at RM 7.2 (Figure 13). East of 290th Avenue SE, where surface flow enters another broad wetland, the Rock Creek channel becomes poorly defined. Flow becomes lost to the ground within this wetland for extended periods except in the wettest times of the year if the groundwater table is high, when the area becomes flooded. The outlet stream from Lake Twelve through Crow Marsh reportedly goes dry at times during the summer.

Rock Creek appears to be hydraulically isolated from the Green River, which runs remarkably close to (within half a mile of) the course of the creek, east of 290th Ave SE (see Figure 13). However, surface water and groundwater flow coming from Crow Marsh flow north from here, rather than taking the much shorter southern route a half-mile to the south, where it could have discharged into the Green River. Some seeps and springs can be observed in the wall of the Green River gorge but the absence of a significant natural streamcourse discharging to the river is thought to have a geological explanation, as described in Section 3.2.1.

For an unknown period of time, there was a 6- to 8-foot-wide diversion channel cut through to the Green River in this vicinity (at Mile 7.2) that resulted in an undetermined loss of flow from the Rock Creek catchment. Flow in the diversion channel was observed by King County during a field check in the spring of 1993 to be around 5 cfs, flowing from the adjacent wetland along Rock Creek (King County 1993). The age of the diversion channel is uncertain but it partially drained the adjacent wetland and diverted some of the flow in Rock Creek to the Green River, thus representing an unaccounted loss of water from the Rock Creek catchment, and potentially affecting surface flows and groundwater levels downstream.

King County (1993) dated the channel to the early 1960s based on a brief comment by Wolcott (1973) regarding the drainage of Lake Twelve; however, Wolcott makes similar statements regarding the drainage of Retreat Lake, which clearly does not drain to the Green River. The diversion channel was eventually blocked off by King County in 1997.

Surface flow along the full 8 miles of Rock Creek from its exit at Lake Twelve is rare. In the upper catchment, between RM 6.5 and RM 2.5 (just upstream of the

Clark Springs Watershed), surface flow in Rock Creek is often completely lost to groundwater and the creek exhibits an intermittent nature for most of this reach. This groundwater/surface water interaction is described in greater detail in Section 4.

Several small tributaries drain into Rock Creek within the upper catchment, especially off Ravensdale Ridge. Flow in these channel is apparently flashy in nature, consisting of storm runoff and interflow from the hillsides, with no appreciable component of baseflow due to the relatively low permeability of the till and bedrock forming the hills. Away from the course of Rock Creek, surface drainage on the valley floor is poorly developed due to the high permeability of the highly porous glacial deposits, as discussed in Section 3.1. A small creek named locally as Sugarloaf Draw also flows intermittently off the western flank of Sugarloaf Mountain (Figure 13), but its flow disappears into the glacial deposits of the valley plain within a short distance.

The course of Rock Creek extends north through a series of riparian wetland complexes in sub-basin 7A (Figure 13), following the railroad track around the foot of Ravensdale Ridge and into the town of Ravensdale. From here, it crosses the valley to the northern side and is joined (at Mile 2.5) by a tributary from the east known locally as Georgetown Creek. Georgetown Creek appears to originate 0.7 mile east of the confluence at a small possibly man-made pond that dams flows from local springs near the end of SE 268th Street, west of Landsburg Road SE (Figure 2). Flows in this reach are intermittent, only occurring under relatively wet conditions.

West of 268th Avenue SE (Ravensdale), the course of Rock Creek then passes through the small subdivision of Bridle Trails before entering the eastern end of Clark Springs Watershed. East of the watershed, where the first occurrence of perennial streamflow is generally reported, a discernible flow or spring is not evident because the creek bed has been partially blocked by a small dam that impounds a portion of the flow. Downstream from this point, perennial flow in Rock Creek follows a defined channel mixed with sections where it traverses a broad diffuse wetland within the City's watershed property. Springs and seeps are abundant in this reach, with baseflow to Rock Creek increasing substantially through to the City's CSWSS facilities, before the creek passes under Kent-Kangley Road.

### *Lower Rock Creek*

The direction of flow in Rock Creek changes from westward to northward at Clark Springs, and the river loses almost 180 feet in elevation between there and the Cedar River. There are no tributaries to Rock Creek in the lower reach. The

streambed is characterized by reaches of relatively flat, sluggish flow, in broad diffuse wetland conditions, alternating with steeper reaches where the gradient is much higher and flow typically occurs in a much more defined down-cutting channel. The geomorphology of the active stream channel downstream of Clark Springs is described more fully in the Geomorphic Study (Appendix D of the Clark Springs BA).

The lateral boundaries of the lower Rock Creek catchment are poorly defined within the relatively flat topography of the plateau south of Maple Valley. The creek itself follows a V shaped valley as it flows through Rock Creek Natural Area (Figure 13), a recent addition to King County's Parks System.

The creek then enters its steepest reach, losing 100 feet within ¼ mile as it drops down the south flank of the Cedar River valley and onto the alluvial floodplain. In this reach, it passes in a culvert beneath the Cedar River Pipeline (the location of King County's Gage 31L). On the floodplain, it passes through another culvert below SE 248th Street, where past and present stream gaging is conducted by USGS (Station 12118500), and then follows a channelized bed to its mouth at the Cedar River.

According to older USGS topo maps, the lowest reach of Rock Creek used to flow due east from SE 248th Street, with the Cedar River confluence some 600 feet upstream of its current location (see Figure 8). It appears that the course of the creek was diverted into a man-made channel flowing north at some time during the 1950s or 1960s — probably around the time when the current residential properties in the floodplain were first developed.

### 3.3.2 Surface Water Bodies

Apart from Rock Creek itself, the primary surface water features occurring in the project area include small lakes, perennial and intermittent creeks, and rivers. As shown on Figure 13, Lake Twelve and Retreat Lake lie in the upper catchment, and Ravensdale Lake is situated in the Ravensdale outwash aquifer channel. Various smaller lakes occur throughout the project area. The physical attributes of the larger surface water bodies within the catchment and their relationship to the hydrology of Rock Creek are summarized as follows.

#### *Lake Twelve*

Lake Twelve is surrounded by bedrock hills and is probably underlain by a veneer of glacial till that promotes the storage of runoff from the surrounding hills. The lake provides a relatively consistent outflow into a broad flat-lying wetland area to the east known locally as Crow Marsh. Inventoried by King

County as Wetland 91, Lake Twelve has an area of 43.2 acres, a maximum depth of 28 feet, and a surface elevation of 718 feet MSL (Wolcott 1973). Its role as part of the Rock Creek system is discussed in Section 3.3.1.

### *Retreat Lake*

Although thought to be a groundwater-fed lake, the water surface elevation is higher than the underlying aquifer, so it is considered to be perched on low-permeability sediments that separate it from the underlying aquifer. Retreat Lake has an area of 52.7 acres, a maximum depth of 50 feet, and a surface elevation of 731 feet MSL (Wolcott 1973). Outflow at the southwestern end of the lake flows a short distance before disappearing into a sinkhole where it recharges groundwater in the underlying aquifer.

### *Ravensdale Lake*

Although strictly not located within the defined catchment boundary for Rock Creek, Ravensdale Lake merits mention because of its critical role in an important aspect of the hydrology of the upper catchment—inter-basin groundwater loss. As described later in Section 3.4.5 and in Appendix F (Section 2.1.2), a substantial flow of groundwater occurs out of the Rock Creek catchment via the Ravensdale aquifer channel. Ravensdale Lake is a groundwater lake located within this channel. It has an area of about 18 acres and a water elevation of around 580 feet MSL (Wolcott 1973).

### *Hidden Lake*

Hidden Lake is a shallow lake that forms seasonally in a flat depression northeast of Ravensdale (Figure 13). Inventoried by King County (1993) as Wetland 82, it represents a hydrologically isolated feature in the northern part of the upper Rock Creek catchment. The depression is mapped to contain fine-grained soils and peat, which help to maintain wetland conditions by perching precipitation for extended periods, encouraging saturated soil conditions.

### *Wetlands*

Numerous wetlands are associated with Rock Creek. There are two main forms of wetland, mainly within the upper Rock Creek catchment:

- Riparian wetlands along the course of Rock Creek; and

- Isolated depressional wetlands, probably associated with kettle holes or other closed depressions, and generally located away from the course of Rock Creek.

The riparian wetlands along Rock Creek play an integral role in the hydrology of the creek, and are strongly controlled by water levels in the underlying aquifer, as described in Section 3.4.

The isolated depressional wetlands perform a less-critical hydrologic function, perching or trapping seasonal recharge on a localized layer of finer-grained low-permeability sediments that have accumulated over time within each depression. Evaporative losses from the well-developed vegetation in such wetlands are relatively high, because the fine-grained soils retain moisture well into the summer months. Groundwater recharge from such wetlands is likely limited for related reasons: low-permeability soils prevent significant deep percolation that could otherwise recharge the water table in the underlying aquifer. Such wetlands provide minimal flood storage because they are disconnected from the main stem of Rock Creek.

### 3.3.3 Streamflow Data

A detailed review and discussion of current and historical streamflow data that are available for Rock Creek are presented in this section. Streamflow data provide vital information on the characterization of the catchment and are essential to the modeling efforts being undertaken to simulate surface water and groundwater flows in the system that support both the CSWSS facility and the perennial downstream reach of Rock Creek.

Important findings from the analysis of streamflow data relate directly to resolution of hydrogeologic objectives set out for in the Introduction (Section 1.2). Historical and current data on streamflow in Rock Creek are available from a number of gage locations:

- USGS Gage 12118000;
- USGS Gage 12118300;
- USGS Gage 12118400;
- Clark Springs Flume, operated by the City of Kent;
- USGS Gage 12118500; and
- King County Gage 31L.

In addition, various manual measurements of flow in Rock Creek have been made by the City of Kent and King County as part of previous studies, and by Pentec's fish biologists in support of the IFIM Habitat Evaluation conducted as

part of this Clark Springs BA (see Appendix H). Gaging locations are shown on Figure 13 and referenced in the text to River Miles (RMs) measured from the mouth of Rock Creek.

### *USGS Gage 12118000 — Landsburg Diversion*

USGS Gage 12118000, was located at the Rock Creek diversion at Landsburg (latitude 47°23'30", longitude 121°58'40"), and operated from July 1, 1932, through September 30, 1948. This location is on a different Rock Creek on the north side of Cedar River, and should not be confused with the Rock Creek that runs through Clark Springs.

### *USGS Gage 12118300 — Eastern End of Clark Springs*

USGS Gage 12118300, located on Rock Creek near Ravensdale at RM 2.6 (latitude 47°21'45", longitude 121°59'45"), operated from October 1, 1956, through September 30, 1958. These coordinates place the gage at the eastern end of the Clark Springs Watershed (Figure 13) providing a rare and valuable record of measured flows entering the Clark Springs Watershed. The data set for this gage for Water Years[1] (WY) 1957 and 1958 is plotted on Figure 14a, (together with the corresponding record from USGS Gage 12118400 located at the western end of the watershed, as discussed below).

Comparison of the two data sets provides an indication of the typical changes in streamflow that occur through the Clark Springs Watershed during a period when the CSWSS was under construction but not operating (more detail on the history of the facility is presented in Section 4.2.1). Peak flows during periods of high runoff were generally similar at both locations, showing the relatively small contribution to direct runoff that comes from the adjacent hillslopes forming most of sub-basin R2 (Figure 13).

During drier periods, the flow at the upstream gage (12118300) approached zero; the difference between the two gages is taken to represent baseflow discharge to Rock Creek at Clark Springs. The third line on the graph on Figure 14a records this difference in flow, and shows a relatively consistent baseflow quantity ranging up to 10 cfs, dropping to 3 or 4 cfs in the late summer.

The data also demonstrate an important function of the upper catchment in controlling baseflow: the lower overall winter flows in WY 1958 produce

[1] A *Water Year* runs from October 1 of the preceding year, through September 30.

noticeably less baseflow by the end of the summer (~3 cfs), whereas the wetter winter of WY 1957 produced noticeably higher late summer flows (~6 cfs). The late summer flow is controlled in part by the volume of water that has been stored in the upper catchment aquifer over the preceding winter months as a result of groundwater recharge.

### *USGS Gage 12118400 — Kent-Kangley Road Crossing*

USGS Gage 12118400, located in Rock Creek (RM 1.6) at State Highway 5A (now SH 516 — Kent-Kangley Road) near Ravensdale (latitude 47°21'45", longitude 122°00'35"), operated from July 1, 1956, through September 30, 1962. This location is very close to the place where Clark Springs Flume was installed a few years later (see below). The data set for this gage for WY 1957-62 is plotted on Figure 14b, together with the corresponding record from USGS Gage 12118500 (at SE 248th Street; see below).

The data comparison is important because it represents flow conditions in the perennial downstream reach of Rock Creek before and after the construction of the CSWSS facilities by the City of Kent. The difference in daily flows between the two stations (the third line on Figure 14b) may be attributed to three significant hydrologic components that potentially affect flow in this lower reach:

1) Negative values represent streamflow losses to groundwater;

2) Positive values in the summer months would represent a gain in streamflow due to baseflow discharge from groundwater; and

3) Positive values coinciding with peak winter flows likely represent surface water runoff from the lower Rock Creek catchment sub-basin (R1 on Figure 13).

The very small negative values (<1 cfs) and the general absence of positive values in the summer months indicate that streamflow gains or losses in the lower reach of Rock Creek due to interaction with groundwater are negligible (i.e., less than 1 cfs). This is a key finding that has a substantial influence on the modeling and understanding of flow dynamics in the Rock Creek system.

USGS Gage 12118400 was reactivated in May 2001 following a coordinated effort between the City of Kent and the US Geologic Survey to improve the quantity and quality of streamflow data available for Rock Creek. This work is described in the next section.

### *Clark Springs Flume*

In 1969, the City of Kent installed a Parshall Flume in Rock Creek (RM 1.6) at the downstream end of the Clark Springs Watershed. The 3-foot-wide flume is located 40 feet upstream of the Kent-Kangley Road crossing, at approximate elevation 562 feet MSL (HC-6 on Figure 13). The flume is located just south of Kent-Kangley Road. Since at least 1985, the City has routinely observed water levels in the flume by making manual readings of a staff gage each day (except weekends and holidays) and converting the flow depth to streamflow using a standard theoretical equation for flow through a 3-foot-wide Parshall Flume. Due to the low overall height of the flume, it becomes overtopped when the water depth exceeds 2 feet, which corresponds to a theoretical flow of 35 cfs. The flume, therefore, does not record peak flows with any degree of accuracy.

Some time after the installation of King County Gage 31L downstream of Clark Springs (see below), discrepancies between the two gages were suspected, especially for the comparison of low-flow measurements between the two gages (Figure 14d). There have been extensive discussions between the City and King County over the intervening years, with the City commissioning independent hydraulic analysis and calibration of the flume against manual measurements of the flow. This work indicated the Parshall Flume was operating in a submerged condition that prevented the formation of critical flow within the throat of the flume. Alternative empirical flow curves were developed based on the calibration measurements; these curves gave consistently lower flow values for a given water stage.

On August 18, 1999, the hydraulic conditions at the flume were improved by removal of rocks (placed by vandals) downstream in an effort to reduce tail-water levels and to re-establish critical flow through the flume. This was only partially successful and resulted in the development of a third equation for the conversion of flow depths to flow rates.

Following a request from the City of Kent, the USGS established a new gaging station at this location, using the existing flume. A temporary gage was installed on May 1, 2001, consisting of a pressure transducer and datalogger located in the approach to the flume. This effectively reactivates the previous USGS Gage 12118400 (see above), which operated from June 1956 through September 1962. Working with the City of Kent, the USGS subsequently installed a permanent gage with telemetric capabilities for real-time acquisition of streamflow data from the Clark Springs Flume. The streamflow data collected through the end of WY 2002 are graphed on Figure 14c. Real-time data from this gage can viewed over the Internet (USGS 2003).

### *USGS Gage 12118500 — SE 248th Street Culvert*

The most extensive record of streamflow in Rock Creek comes from a USGS-operated water stage recorder that was located on the left bank of Rock Creek, 650 feet upstream from the mouth of Rock Creek (RM 0.2) – latitude 47° 22′ 48″, longitude 122° 00′ 58″ – at an approximate elevation of 425 feet MSL. This location was 50 feet upstream of the SE 248th Street culvert (Figure 13). Prior to March 16, 1953, the gage was located 50 feet downstream of this location at an elevation approximately 1 foot lower.

Detailed streamflow records, including 15-minute readings, are available from June 1945 through September 1973. Relatively complete streamflow records for WY 1946 through 1973 (in total, 28 consecutive water years) are available. The average discharge measured over the 28-year period of record is 19.5 cfs, which is a gross number that includes flood peaks as well as sustained periods of low flow that typically occur in late summer. A flow statistic that is more representative of the creek is the median daily flow of 13 cfs – defined as the flow that is exceeded 50 percent of the time. The full streamflow record is presented and analyzed in detail as part of the HSPF modeling study presented in Appendix C of the Clark Springs BA. Some additional observations and interpretations of the long-term record provided by these streamflow data are presented in Section 3.3.4.

Following a request from the City of Kent, the USGS re-established Gage 12118500 in the vicinity of the SE 248th Street culvert on May 1, 2001. The temporary gage consists of a pressure transducer and datalogger located 15 feet downstream of the box culvert. USGS are working with the City on the installation of a permanent gage with telemetric capabilities for real-time acquisition of streamflow data. The streamflow data collected through the end of WY 2002 are graphed on Figure 14c.

The new USGS gages (12118400 and 12118500) now provide more accurate data for streamflow in the lower reach of Rock Creek. Figure 14c shows that streamflow at both locations are almost identical for low-flow conditions, confirming the interpretation presented earlier that groundwater exchanges with the creek (i.e., baseflow gains and losses) in this reach are negligible. Daily peak flows during the winter range from 2 to 20 cfs higher at the downstream gage, possibly reflecting slightly increased runoff due to recent development in lower Rock Creek catchment.

Note from Figure 14c that the calculated summer baseflow component shows a slight declining trend throughout the summer, with small positive values becoming small negative values by late summer. This may reflect limited

groundwater inflow (<0.5 cfs) becoming a small loss of flow to groundwater (<0.5 cfs) by late summer. (Note: Evaporative losses through the reach are estimated to peak at no more than 0.01 cfs.)

### *King County Gage 31L*

Starting in November 1994, King County's Department of Natural Resources re-established a water stage recorder at the approximate location of the USGS Gage 12118500 (described above) at near RM 0.2 (Figure 13). 15-minute water stage readings have been collected since that time, although a significant portion of the record is affected by missing data (typically at least 30 days missing in each water year). The gage itself was washed out in a major storm event early in January 1997; at that time, the gage was relocated from the SE 248th Street culvert to its existing site upstream of the culvert that carries Rock Creek under the Cedar River Pipeline (RM 1.1).

The gage consists of a pressure transducer located in a stilling well on the left bank of the stream. A datalogger records the water stage every 15 minutes, the data are downloaded by technician every 5 to 6 weeks. Data are then published on King County's website. A staff gage showing flow depths is located near the transducer but use of this for flow estimation requires a rating curve obtainable from King County.

King County acknowledges that the gage location and conditions are not ideal for low-flow measurements (David Funke, personal communication 2000), which is visually evident at low flows when the stream bifurcates at different levels to flow through the three different sections of the culvert, the creek bed being broad and uneven at this location, with numerous rocks and boulders. By contrast, preferred gaging conditions would include a narrower, more incised streamflow channel. Low-flow readings are consequently prone to error.

### *Manual Measurements*

Systematic manual measurements of streamflow have been collected by Pentec/Hart Crowser at various times during the Clark Springs BA project at a 18 points along Rock Creek. These data are presented in Table 1.

Flow measurements taken in late September 2000 show typical late-summer low flows. In WY 2001, which was a very dry year, no significant flow was observed in Rock Creek upstream of the Clark Springs Watershed until the end of March 2001. Flows had been observed (but not measured) at the outlet from Lake Twelve during the winter, but the stream disappeared into the wetland east of 290th Ave SE.

As streamflows increased during the spring, flows in upper Rock Creek extended further downstream but always decreasing until a point where the upper creek became dry. During April 2001, total loss of streamflow persisted at the northern end of Ravensdale Ridge, with no flow recorded at 268 Avenue SE, despite increasing discharge rates from Lake Twelve. The highly permeable outwash channel north of Ravensdale Ridge appears able to absorb streamflow in all but the wettest conditions, as was observed in the McCann study (GeoEngineers 2000).

In addition to the readings listed here, detailed flow and channel cross section measurements were made by MCS Environmental for the IFIM Study (Appendix H of the Clark Springs BA).

### 3.3.4 Streamflow Analysis

The 28-year data record from USGS Gage 12118500 has been analyzed to look for possible evidence of changes in the streamflow characteristics of Rock Creek during the period of record from WY 1946 through WY 1973. Streamflow records have been used to develop the following hydrologic characteristics for the Rock Creek catchment:

- Average Annual flow;
- Basin Water Yield, the amount of precipitation that becomes streamflow;
- 7-day Low-flow Analysis; and
- Flood Flows.

#### *Average Annual Flow*

The first analysis uses the double-mass curve technique to test the consistency and uniformity of flow data recorded at the gage. For each water year in the data record, values of total annual streamflow for Rock Creek are added cumulatively and plotted against total annual flow in Cedar River, as measured at USGS Gage 12119000 in Renton (see Figure 15a). A change in slope of the double-mass curve is discernible around 1965 or 1966, since which time the slope of the curve shows a visible reduction.

The change in slope of the double-mass curve represents a reduction in average streamflow in Rock Creek from 21.0 to 16.4 cfs. The change does not appear to be attributable to a reduction in precipitation (the mean precipitation at Landsburg increased slightly in the period 1966-73). The timing of the apparent reduction in streamflow coincides approximately with the Green River diversion (see Section 3.3.1), which is dated to the early 1960s, and the start of water supply withdrawals from Clark Springs by the City of Kent (see Section 4.2.1).

### *Basin Water Yield*

The second analysis considers the total annual water yield of the Rock Creek catchment, as measured at USGS Gage 12118500, which is plotted against the corresponding mean annual precipitation for the catchment (see Figure 15b). Although the relationship shows substantial scatter, the underlying trend for the 20-year period from WY 1946-65 shows a correlation with higher basin yields when compared with the subsequent eight water years before the gage was removed. Note that both trends are parallel, suggesting that the underlying trend has shifted by a uniform amount. The change in basin yield between the two data sets translates to a change in streamflow of approximately 6 cfs.

Annual water yield from the catchment is partially correlated with annual precipitation (regression coefficient, $r = 0.55$). To remove the influence of variability in precipitation, we normalized annual water yield by dividing by annual precipitation. On this basis, the average annual water yield for the catchment (expressed in inches of streamflow per inch of precipitation) decreased from 0.34 inch prior to 1966 to 0.24 inch after 1966. This difference translates to a drop in average flow rate of around 6 cfs for the post-1966 water yield.

### *Low-Flow Analysis*

Seven-day low flows have been calculated for each of the 28 Water Years in the streamflow record from USGS Gage 12118500 (Figure 16a). The resulting data points are grouped into two sets with a break at WY 1966, and plotted as a probability distribution (Figure 16b). The pre-1966 data show a median 7-day low flow of 4.5 cfs, with a range of 1.5 to 6.7 cfs. The post-1966 data give lower values, with a shift of about 3 cfs evident between the two data sets.

The analysis of streamflow data suggests that a systematic reduction in Rock Creek streamflow occurred in the 1965-66 timeframe and was sustained through the end of the available data record for USGS Gage 12118500. The implication has been made by King County that extractions of water from the Clark Springs to supply the City of Kent are the primary cause of loss in streamflows in Rock Creek from this time onward (King County 1993). Consideration should also be given to the effect of the Green River diversion that King County noted as flowing at 5 cfs in 1993 (see Section 3.3.1). King County estimates that the diversion has operated unchecked "at least since the early 1960s" and has likely impacted total flows from the catchment since this time. The Green River diversion was blocked off by King County in 1997.

### *Flood Flows*

The hydrology of the Rock Creek Catchment can be characterized in terms of peak flows as defined for flood flow analysis. Sumioka et al (1997) analyzed the historical record for USGS Gage 12118500 to develop flood probabilities, or the likelihood that the maximum streamflow recorded in any one year would exceed the listed flood flow:

| Return Period in Years | 2 | 10 | 25 | 50 | 100 |
|---|---|---|---|---|---|
| Exceedance Probability | 0.5 | 0.1 | 0.04 | 0.02 | 0.01 |
| Flood Flow in cfs | 82 | 167 | 211 | 244 | 276 |
| 95% Confidence Interval | 68 to 98 | 135 to 221 | 166 to 293 | 189 to 350 | 210 to 408 |

It should be noted that this analysis emphasizes the maximum flows seen in the basin resulting from isolated and, by definition, relatively rare major storm events; these data should not be used to characterize average flows in Rock Creek, which are substantially less.

## 3.3.5 Hydrologic Modeling

The hydrologic characteristics of the Rock Creek catchment has been evaluated in detail for the Clark Springs BA as part of the HSPF modeling task (Appendix C). The HSPF model seeks to simulate the hydrologic response of the catchment using the Hydrologic Simulation Program — Fortran. HSPF is a continuous simulation model that represents the main hydrologic processes operating within the catchment that contribute to runoff manifest as streamflow within Rock Creek.

Inputs to HSPF include a breakdown of the basin into a series of sub-basins in which land use, soil type, average slope, and vegetation are characterized by area (Figure 17). Hydrologic parameters within the model are assigned to the various soil and vegetation types, which control the response to precipitation events (rain and snowfall), including such functions as evapotranspiration, surface runoff, infiltration, soil moisture storage, interflow, and deep percolation below the soil layer. Precipitation is input as a time-series developed from temporal and spatial analysis of precipitation recorded at stations throughout the region to represent as closely as possible the actual precipitation history for each catchment sub-basin.

HSPF simulates the various processes throughout the catchment, aggregates the flows generated from surface runoff, interflow, and baseflow from groundwater in each sub-basin to generate synthetic streamflow hydrographs that can be

compared directly to streamflow data measured at gaging stations within the catchment. The model fit is improved by a process of calibration in which the model parameters for the various land types are adjusted until a good match to the overall hydrologic record is obtained, including both storm peaks and periods of sustained low-flow.

Using the HSPF model, it has been possible to represent our understanding of the surface water and groundwater characteristics of the catchment to simulate the historical record of streamflows observed in Rock Creek with a reasonable level of accuracy. The HSPF model included representation of a number of key features described in this report, including the Green River diversion, and the losses of groundwater flow from the Rock Creek system at Ravensdale and Landsburg.

## *3.4 Hydrogeology*

This section describes the basic hydrogeologic aspects of the Rock Creek catchment, with reference to the geologic units in which the aquifers occur, and the processes controlling the occurrence and movement of groundwater within the catchment. These processes include:

- Infiltration and recharge;
- Runoff and interflow; and
- Groundwater flow, discharge, and levels.

Much of the information and understanding we have gleaned about the groundwater system in the Rock Creek catchment has been incorporated into the groundwater flow model, which is reported separately in Appendix F of the Clark Springs BA.

### 3.4.1 Hydrostratigraphic Units

The hydrostratigraphic units of significance to the hydrology of Rock Creek are primarily two-fold: the unconsolidated glacial deposits that contain the surficial aquifer; and the underlying bedrock which is of generally low permeability and forms an effective base for the active groundwater system in the region.

The hydrostratigraphic units identified in this report were originally presented in City of Kent's Wellhead Protection Plan Report (Hart Crowser 1996) and are consistent with the nomenclature used in the SKCGWMP Background Data Report (1991), USGS reports (Vine 1969), and Cedar River Conditions Report (King County 1993).

### *Shallow Unconfined Recessional Outwash Aquifer*

The primary hydrostratigraphic unit is composed of coarse glacial materials (mainly sand and gravel) forming the recessional outwash, although in some areas may include less coarse and more densely compacted advance outwash. Coarser portions of the ice-contact deposits are difficult to distinguish from the outwash materials and behave in a similar manner hydrogeologically; therefore, they are considered to be part of the shallow aquifer unit.

In places, the recessional outwash aquifer may be underlain by glacial till lying directly on the bedrock surface, or overlying the advance outwash. The till appears to be absent over large areas of the catchment, having likely been scoured out at some stage during the development of broad outwash channels as described in Section 3.2.2.

The hydraulic conductivity and aquifer transmissivity of the unit are generally high but these aquifer properties vary over a wide range, as described in more detail in the Modflow modeling report (Appendix F). Aquifer storativity is assumed to be typical for a shallow unconfined system (i.e., around 0.2, equivalent to a drainable porosity of 20 percent). The lateral extent of the unconsolidated recessional outwash sediments that comprise the shallow aquifer within the project area is shown on Figure 6.

### *Vashon Till Aquitard/Perching Layer*

The Vashon till is discontinuous over the project area. Portions of the ice-contact deposits that are composed of finer-grained sediments (e.g., in the vicinity of Retreat Lake) behave in a similar manner hydrogeologically; therefore, they are considered to be part of the till perching layer. The till mostly occurs as a veneer blanketing the lower slopes of the surrounding bedrock hills (Figure 6).

In this situation, the till impedes infiltration and encourages runoff from the hillslopes. The upper portion of the till is typically weathered with higher permeability that can also provide a pathway for shallow interflow. Both these mechanisms are considered to convey water from the flanks of the hills to the adjacent floor of the upper catchment, where such flows then infiltrate easily into the recessional outwash aquifer.

In localized areas, the till unit may also form a potential aquitard or perching layer between the shallow recessional outwash and the deeper advance outwash, but there is very little evidence of more than one potentiometric surface (Robinson & Noble 1995).

*Tertiary Bedrock*

A groundwater flow system likely exists within the bedrock, dominated by shallow gravity-driven flow through a network of fractures in the upper surface of the bedrock. Given that estimates of bedrock permeability are very low relative to the recessional outwash aquifer, the quantity of water moving through the bedrock system is likely only a small fraction of the flow occurring in the shallow aquifer (on the order of 1 percent). With increasing depth of burial beneath overburden, these fractures tend to close up, such that their flow capacity is dramatically reduced.

For the Clark Springs BA, we have assumed that the bedrock is relatively impermeable; that the amount of flow occurring in the bedrock is within the margin of error for our overall water balance; and can be ignored for practical purposes.

### 3.4.2 Infiltration and Recharge

The Rock Creek catchment is characterized by the direct infiltration of precipitation into the recessional outwash forming the shallow regional aquifer; possible localized perching in ice-contact deposits; and a high sensitivity to winter precipitation, with snow or frozen ground conditions inhibiting infiltration until temperatures rise, when percolation of snowmelt and floodwaters is rapid.

The Rock Creek catchment remains one of the least developed in the Puget Sound, but available land is coming under increasing pressure for development. Our assessment of land use distribution throughout the catchment in 1999 is shown on Figure 17. Changes due to development have an important impact on infiltration and groundwater recharge, because the process of development usually involves the removal of natural or second-growth vegetation (typically forest) followed by its replacement with pastureland, grassland, lawns, driveways, parking lots, and buildings.

These latter surfaces are impervious and shed almost all incident precipitation as surface runoff. However, due to the unique nature of the Rock Creek catchment, this runoff rarely contributes directly to streamflow because the surface soils in the catchment are so permeable. Surface runoff, therefore, generally infiltrates through the adjacent soils and recharges the underlying groundwater, except when the ground is frozen, or the underlying water table is close to or at the surface. For short periods during the wetter winters when such conditions exist, runoff from impervious surfaces, as well as from highly permeable but fully saturated soils, does get conveyed rapidly to Rock Creek, creating relatively high flood flows that are a rare feature of the catchment.

The infiltration and recharge mechanisms and their variations with different land uses and soil types in the catchment are key features of the HSPF modeling being done to simulate the hydrology of Rock Creek (see Appendix C). The model generally represents the hydrologic complexity and function of the catchment quite well, with low and intermediate flows generally well matched. However, HSPF does not simulate the occurrence of a rising water table in highly permeable soils, which creates high flood runoff in Rock Creek, so the matching of peak flows using the HSPF model of the catchment is somewhat problematic.

### 3.4.3 Runoff and Interflow

Recharge is enhanced at the margins of the valley plain as a result of surface runoff and interflow from the surrounding hills. The bedrock forming the hills is of low to moderate permeability, but the flanks of the hills are mantled with glacial till that is even lower in permeability, reducing deep percolation and encouraging runoff.

Where the surface of the till is weathered, it becomes more permeable, allowing shallow infiltration of precipitation to saturated the near-surface soil. The steep hill slopes then encourage lateral movement of this infiltrated water, which moves down-slope at a slower speed than overland flow, creating a delayed component of runoff characterized as interflow. When these flows reach the highly permeable soils of the valley floor, they usually infiltrate rapidly to recharge the groundwater. However, when the water table is already high, the interflow contributes directly to surface flow and runoff.

A special case of runoff and interflow occurring within the upper Rock Creek catchment is the perched groundwater system within the ice-contact deposits (Figure 6) that appears to sustain the hydrology of Retreat Lake. The elevation of the water level in the lake (731 feet MSL) is significantly higher than groundwater in the adjacent recessional aquifer, and is believed to be sustained by discharge from a shallow perched groundwater system within the less permeable ice-contact deposits, which underlie the immediate surface catchment around the lake. Storage of the high rainfall, followed by slow release over the spring and summer months as flows from the lake decline, are thought to be sufficient to maintain the lake throughout the year. Leakage directly from the lake is thought to be low since the lake does not dry up in the summer.

### 3.4.4 Groundwater Flow

The groundwater flow system within the upper catchment forms a shallow unconfined aquifer at the base of the recessional outwash unit. In general,

percolating precipitation and runoff from the surrounding hills supply the recessional aquifer with the majority of its water. This flows northwest over the underlying bedrock surface, toward the discharge points that occupy the lowest elevations at the western end of the valley plain. Figure 18 is a map (based on Robinson & Noble 1995) of the potentiometric surface contours within the aquifer that depict this regional flow pattern.

In the southeastern part of the catchment, the saturated part of the aquifer is thin, reflecting the higher elevation and sloping surface of the underlying bedrock forming the western flank of Sugarloaf Mountain, and the limited amounts of accumulated recharge at the limits of the groundwater system. Although a relatively steep gradient is shown, this is deceptive because the aquifer has high transmissivity (usually typified by low gradients), with groundwater flow occurring across the sloping bedrock surface in a manner that is similar to surface runoff. Flow rates are enhanced, and this part of the aquifer dries out readily in the summer. Groundwater modeling of flow patterns in this area proved difficult for these reasons (see Appendix F).

In the northeastern part of the catchment, there is evidence for a bedrock barrier, which limits the extent of the recessional aquifer beneath the Evergreen Acres. A substantial thickness of highly permeable aquifer materials are present to the north and east (King County 1987), but water levels are reported to be significantly deeper in this area than in the rest of the Rock Creek catchment. The area to the northeast of the buried bedrock ridge, though part of the topographically defined drainage area of Rock Creek, is hydrologically disconnected from the rest of the catchment that feeds water to the west, since groundwater flow cannot cross the bedrock ridge. Rather, groundwater is inferred to flow north from this part of the Rock Creek catchment toward the Cedar River.

Further west, the aquifer picks up large quantities of recharge from Rock Creek (the outflow from Lake Twelve), the eastern flank of Ravensdale Ridge, outflow from Retreat Lake, and seepage from the perched groundwater system in the ice-contact deposits around the lake. Groundwater flows from the south and east of the catchment combine within the outwash channel that runs through the Ravensdale area, where very coarse glacial materials account for high aquifer transmissivities and low hydraulic gradients. A substantial amount of groundwater is inferred to flow down the Ravensdale outwash channel and out of the Rock Creek catchment at this point, as described below. Some of the groundwater flow within the outwash aquifer may also be lost to the Cedar River in a similar manner, via the small valley south of Landsburg.

Groundwater remaining in the aquifer continues to flow westward into the narrow valley occupied by Clark Springs Watershed. The recessional deposits appear to thin out at the throat of the Rock Creek valley, and the width of the aquifer is reduced. Furthermore, there is some indication of a shallow bedrock ledge or a till-mantled saddle present beneath the surface of the watershed, upgradient of the CSWSS facility. The elevation of the bedrock in the channel underlying the watershed, appears to force much of the groundwater flow to the surface where it forms Clark Springs, at the headwaters of perennial reaches of lower Rock Creek.

The inferred geologic conditions that give rise to baseflow discharge at Clark Springs also perform an important role in relation to the upper catchment: they provide a buffer to the transmission of any flow effects upstream from below Clark Springs. The most understandable analogy is that of a weir; any amount of flow changes occurring below the weir cannot affect or change the amount of flow coming over the weir. That flow is governed by upstream conditions – not downstream conditions. Although not as visible as a weir, the narrow throat provided by the aquifer channel that passes through Clark Springs Watershed acts as a weir that in part controls the subsurface flow from the upper catchment, while preventing the effect of downstream withdrawals from propagating upstream.

From Clark Springs, a portion of the groundwater water flow remaining in the recessional outwash aquifer follows the course of Rock Creek to the north, with the remainder continuing westward, toward Lake Wilderness. This latter portion leaves the Rock Creek catchment at this point, and contributes to maintaining flows in the Covington Uplands aquifer to the west that feeds a number of important water sources, including the Witte wellfield and Kent Springs.

In the lower Rock Creek catchment, groundwater flow is significantly reduced in volume and significance, compared with the upper catchment, with a substantial portion having left the aquifer as baseflow to the creek, or having left the catchment as aquifer through-flow into the adjacent Soos Creek basin. Although the area is blanketed by similar recessional outwash deposits, these form the southern wall of the Cedar River valley in this area, and there is only a limited catchment area, including the flanks of the small hills to the south. Most precipitation that does not evapotranspirate, in addition to runoff from the till-covered hills, appears to recharge a fairly thin zone of saturation created by the buried south wall of the ancestral Cedar River valley.

Groundwater flow in the aquifer underlying the lower catchment is likely controlled by the shape and topography of the buried bedrock surface and densely compacted older glacial sediments that are almost completely obscured

by recessional outwash in this area. A veneer of saturation likely occurs at the base of the outwash, but levels are generally below the bed of Rock Creek, so additional groundwater baseflow contributes little if at all to the flow in lower Rock Creek.

### 3.4.5 Groundwater Discharge

Groundwater discharges from the upper Rock Creek catchment via two major avenues: the Clark Springs Watershed and the Ravensdale valley. Both discharge points consist of valleys filled with recessional outwash. The high transmissivity of the sediments allow a substantial amount of groundwater flow to leave the upper catchment along these discrete aquifer channels.

The division of flow between the two adjacent valley aquifer channels appears to be controlled by the elevation of the underlying bedrock, and possibly by the distribution and relative permeability of deposits filling the channels. GeoEngineers (2000) provide some evidence for lower-conductivity sediments at the head of the Ravensdale channel, which may limit the amount of flow that gets diverted in this direction. Although the amount of groundwater flow leaving the upper catchment via the Ravensdale aquifer channel is difficult to quantify directly from field data, our modeling studies (Appendix F) suggest it is slightly less in quantity (by 5 to 15 percent) than the groundwater flow through Clark Springs.

Determination of the flow split between the two aquifer channels is based on the overall structure and configuration of our groundwater model (as described fully in Appendix F), and represents one possible scenario. Other refinements and variants to the model could be developed that would give different proportions for the flow split. In Appendix F, we recommend a program of field studies that could be developed to provide better data on the amount of groundwater flow occurring in each aquifer channel.

Some speculation from previous studies also suggests that groundwater might escape the upper valley plain via a trough south of Landsburg, although this has not been confirmed. Earlier groundwater studies (Brown & Caldwell 1980) implied that flow occurred northwestward out of the Rock Creek catchment and into the Cedar River over the whole northern boundary. However, the presence of bedrock hills and areas of till along parts of the northern boundary of the catchment suggests there is a subsurface barrier to northward flow. This may occur as a lip to the buried bedrock surface that is a remnant of the glacial outwash channel, which may have cut down into the underlying bedrock surface before the mass of recessional material was deposited in the channel.

The proximity of Lake Twelve and the adjacent wetland (Crow Marsh) to the Green River gorge would suggest that groundwater discharge occurs from this area to the south. Indeed, earlier maps of groundwater flow patterns in this vicinity (Brown & Caldwell 1980; King County 1987) show a substantial portion of the Rock Creek catchment south of Retreat Lake to be draining southward to the Green River.

The high bedrock walls visible in the incised Green River gorge would tend to confirm modern interpretations that the bedrock surface beneath the plain to the north is relatively high and appears to slope away from the gorge, largely preventing groundwater from flowing over the lip and dropping 200 feet into the Green River below. Conversations with the Park Ranger at Kanasket State Park indicate that there are a number of seeps and springs visible in the north wall of the Green River gorge through this area, suggesting that at least a component of the groundwater in the Rock Creek system is discharged in this way, or via fracture flow through the bedrock.

In our HSPF and Modflow simulations, we have assumed that there is no significant groundwater discharge from Rock Creek to the Green River; however, alternatively modeling scenarios could be developed that allow for this form of groundwater discharge to occur. The difficulty would be estimating (or attempting to measure in the field) the flow volumes involved.

### 3.4.6 Groundwater Withdrawals

The shallow outwash aquifer system underlying the Rock Creek system is a high yielding unit, providing significant domestic and municipal water supplies in the area. It is from this hydrostratigraphic unit that the City's CSWSS facilities extract groundwater; along with a number of other local users. In general, groundwater withdrawals from the Rock Creek catchment fall into four groups:

- Municipal Water Supplies: Clark Springs and the Ravensdale Well;
- Private Water Supply Systems: Evergreen Acres, Retreat Lake, etc.;
- Other wells with water rights; and
- Domestic wells (wells exempt from requiring water rights).

The City's longstanding operations at Clark Springs constitute the largest single groundwater withdrawal from the catchment. These operations are discussed in detail in Section 4.2, but it is important to note here that Kent's operations do not have any impact on the availability and quantity of water resources available in the upper catchment, nor do their operations affect groundwater levels or creek flows in the upper catchment since the hydrogeologic conditions within the Clark Springs Watershed (described in Section 3.4.4) create a threshold

which prevents the effects of withdrawal at the City's CSWSS facilities from propagating upstream.

Other municipal water supplies drawing upon the groundwater resources in the upper catchment include the Ravensdale Well, which is operated by the Covington Water District. The well supplies the town of Ravensdale, a portion of which is located just outside the boundary of the Rock Creek catchment (see Figure 13). Groundwater pumpage from the well has increased steadily over the last 10 years (Figure 19), rising from 20,000 gpd (0.03 cfs) to 50,000 gpd (0.08 cfs) in 2001.

Independent, privately operated water supply systems provide water to subdivisions at Evergreen Acres, Retreat Lake, Lake Twelve, and a number of other locations throughout the catchment. Locations of well-based Class A and Class B water supply systems registered with the Washington State Department of Health (DOH) are listed in Table 2 with their approximate locations shown on Figure 18. Total capacity listed for these systems within the catchment is 4,231 gpm (9.4 cfs). Information on actual water usage has not been obtained at this time but a substantial portion (typically between 70 and 90 percent) becomes return flow to the groundwater system.

Other water rights within sections that are all or partly inside the catchment (including groundwater and surface water sources) are listed in Table 3. The listed annual amounts of these water rights total 1,230 acre-feet per year, equivalent to 1.7 cfs (including a number of rights outside the limits of the catchment).

In addition to users with listed water rights, a large number of wells that do not require water rights provides water to individual homesteads and other properties in the catchment. The number of such exempt wells, based on 1999 land use and well data, is estimated to be 250. At a maximum withdrawal rate of 5,000 gpd per well, this translates to a potential groundwater withdrawal rate of 1.9 cfs but again, most of this will return to the aquifer as groundwater recharge.

The overall impact of most of these withdrawals (with the exception of the Ravensdale Well flow, that leaves the Rock Creek catchment) will be less than the stated amounts because a substantial portion of the water used returns to the aquifer as infiltration or septic flow from drainfields. However, Ecology does not acknowledge the beneficial contribution of such return flows.

### 3.4.7 Groundwater Levels

In August 1993, the City began development of a Wellhead Protection Program for Clark, Kent, and Armstrong Springs. The purpose of the wellhead protection project was to develop a program to protect long-term water quality at these three groundwater sources. Collectively, these facilities provide as much as 65 percent of the City's current water supply.

A monitoring plan was developed to measure groundwater quality and allow early detection of groundwater quality changes. The monitoring program would allow identifying trends and detecting problems before they reach the wellhead. Monitoring of the wellhead includes water level measurement and groundwater quality sampling and analysis of local and sentinel wells. Such wells are usually volunteer domestic source wells located within the aquifer, some distance upstream of the wellhead being protected, and within the calculated 1-year travel time for groundwater flow to the wellhead. Water quality samples are typically monitored on a quarterly to annual schedule, with water levels measured monthly to collect valuable information on the seasonal fluctuation of groundwater levels. In addition, surface water monitoring is used to assess bedrock runoff quality inside of the 1- and 2-year zones. The data collected over the last 5 years from this array of wells illustrate the variation in groundwater levels that occurs seasonally within the catchment.

Groundwater levels in wells within the catchment clearly reflect seasonal recharge (Figure 20), with a long period of recession as the stored water that boosted groundwater levels and increased gradients in the upper part of the catchment during the winter gradually subside into the summer months. The exception is the Retreat Lake well, which varies very little in water level, likely reflecting a perched groundwater system dominated by volume of water stored in the lake.

Seasonal levels may be low or high as a direct result of antecedent rainfall and snowmelt occurring over the previous months or seasons. Wet winters result in particularly high water tables creating flooding conditions along much of the course of Rock Creek. At other times (WY 2001 provides a recent example), rates of groundwater recharge are much reduced as a result of rainfall that is well below normal, and the water table remains below the ground surface throughout most of the upper catchment. Under these conditions, seasonal flow in the intermittent parts of Rock Creek may not occur, or may only occur very late in the season, when sufficient recharge has accumulated to finally raise the water table to ground level.

Additional information on the City of Kent Wellhead Protection Program is available in the Well Protection Program prepared by Hart Crowser (1996). The water level data collected from the monitoring wells from 1997 onward provide important information for the calibration of the Modflow groundwater flow model prepared for the catchment (see Appendix F of the Clark Springs BA).

### 3.4.8 Groundwater Flow Modeling

The detailed information presented above about the groundwater system in the Rock Creek catchment has been incorporated into the groundwater flow model, which is reported separately in Appendix F of the Clark Springs BA. The model applies quantitative analysis to the groundwater system and was developed in concert with the HSPF surface water model described in Appendix C.

The HSPF model is effective in simulating the surface hydrologic processes (evaporation, transpiration, infiltration, runoff, interflow) that determine the fate of precipitation on the catchment and allow the portion, which recharges the groundwater, to be identified and quantified. This forms a key input to the Modflow groundwater model, which provides a more robust and technically accurate description of the way that groundwater moves through the catchment.

The Modflow model was used to examine groundwater flow patterns and quantify portions of the groundwater flow that discharge to Rock Creek, as well as those that discharge out of the catchment. The baseflow discharge calculated by Modflow was used as a comparison with the baseflow quantities calculated in HSPF, and the two models were matched to the extent possible through a process of interactive calibration. Refer to Appendix C (HSPF) and Appendix F (Modflow) for detailed reports on these tasks.

## 4.0 SURFACE WATER AND GROUNDWATER INTERACTION

This section builds on the description of the Rock Creek catchment provided above and examined in detail as part of the modeling tasks to explain the hydrologic functions of the stream and aquifer system, and how they interact throughout the length of Rock Creek. The description is divided into three sections corresponding to the three hydrologic regimes—Upper Rock Creek Valley Plains, Rock Creek at Clark Springs, and Lower Rock Creek—identified within the Rock Creek catchment.

## 4.1 Upper Rock Creek Valley Plain

The occurrence and quantity of water in the upper Rock Creek catchment governs both the availability of water for withdrawal by the City at Clark Springs and the amount of streamflow in lower Rock Creek. As such, the upper catchment represents a critical control on the hydrology of the entire Rock Creek system.

Flow in the upper reaches of Rock Creek depends primarily on groundwater levels along the course of the creek. Levels rise quickly, usually in the early winter, in direct response to increased seasonal precipitation that percolates rapidly through the highly permeable soils, once any soil-moisture deficits have been satisfied. If levels rise to ground level, especially in the wetlands and other low spots that form the creek channel between Mile 6.5 and Mile 3, Rock Creek will flow from Lake Twelve through to the culvert at Mile 4.8.

Downstream of this point, the creek enters the major ancestral east-west outwash channel that consists of very permeable recessional outwash deposits. Depending on groundwater levels in this part of the system, the creek may be gaining or losing. Early in the winter season, conditions are likely to be such that the creek will lose water in this reach as groundwater levels may still be below the creek bed. Later in the typical winter season, as water levels rise further throughout the shallow aquifer, these reaches will convert from losing to gaining conditions, and flows in Rock Creek will increase further downstream.

More complex dynamic conditions may prevail during significant storm events, with substantial surface flows in the upper reaches extending downstream to a point where losing conditions may still prevail. GeoEngineers (2000) documented such a condition at the McCann Property near Ravensdale during a storm on January 12, 2000. A peak streamflow of 13.3 cfs was recorded crossing beneath Ravensdale Way (HC-12 on Figure 13) whereas the flow crossing 268th Avenue SE (HC-11) was 8.4 cfs. But, just 1,500 feet further downstream, a flow of only 0.2 cfs was recorded. Almost all of the streamflow — 13 cfs (5,800 gpm) — was infiltrating into the highly permeable outwash deposits over this remarkably short distance. Groundwater monitoring at the time showed the water table to be 3 or 4 feet below the creek bed in this reach.

## 4.2 Rock Creek at Clark Springs

This section presents a detailed description of the water supply facilities and operations maintained by the City in the half-square mile area of the Clark Springs Watershed on Rock Creek. It includes information about the CSWSS facilities and how they are constructed, because this has a bearing on how their

operations interact with flows in Rock Creek. The hydrogeologic setting and geologic constraints of the location also play a role in this aquifer/streamflow interaction.

Water production from Clark Springs in previous years is reviewed, and the details of two monitored system tests are provided to illustrate the concept of baseflow capture that characterizes the effect CSWSS operations have on Rock Creek under median flow conditions. The detailed work presented here demonstrates that further systems tests should be performed to quantify interaction effects at low-flow conditions, when more of the CSWSS supplies are drawn from groundwater that does *not* discharge as baseflow, and the impact to Rock Creek is proportionally reduced.

### 4.2.1 History

The natural springs forming the headwaters of perennial flow in the lower reaches of Rock Creek have been used as a water supply by the City of Kent since 1957, although Irving Clark had the foresight to secure water rights at Clark Springs as early as 1930. The water rights that have been obtained at Clark Springs are listed below:

| Permit | Priority Date | Name of Source | Instantaneous Flow Limit, *Qi* in gpm | Annual Flow Limit, *Qa*, in acre-feet/year |
|---|---|---|---|---|
| 3107-A | 2/57 | Clark Springs Trench | 2,250 | 1,350 |
| 7232-A | 10/31 | Rock Creek | 2,244 (5 cfs) | 3,600 |
| 7660-A | 2/69 | Clark Springs Wells | 5,400 | 8,710 |

The CSWSS serves as the City's primary water source and is used on a continuous basis throughout the year. The City established the first extraction facilities in the form of two smaller infiltration galleries in 1957, located to the west of the current gallery (Figure 21).

CSWSS is comprised of three separate, but conjunctively managed primary sources and/or water rights: Clark Springs Trench, Rock Creek Surface Water Diversion, and Clark Springs Wells. Each of these rights/sources draw upon the same shallow recessional outwash aquifer source and are in hydraulic continuity with each other.

Given the close hydraulic connections among these sources, the City has found it most effective from a production and environmental protection standpoint, to operate these sources in a conjunctive manner. Put another way, the sources

are operated as a wellfield, whereby the instantaneous and annual withdrawals of the system are limited to the cumulative totals allowed under the combined surface water, springs, and groundwater rights (i.e., 9,894 gpm for instantaneous flow, *Qi*, and 13,660 acre-feet/year (af/yr) for total annual withdrawal, *Qa*).

### *Clark Springs Trench—Certificate No. 3107-A (Supplemental)*

Clark Springs Trench is a certificated, spring-based source with an authorized instantaneous quantity *(Qi)* of 2,250 gpm and an annual quantity *(Qa)* of 1,350 af/yr, that is supplemental to Clark Springs Well Right Certificate No. 7660. The water right has a priority date of 1957. The water right's purpose of use is for "municipal purposes" and the designated place of use is the "City of Kent." The right was initially issued as a primary right and perfected as such. In 1969, the authorized *Qi* and *Qa* became subject to the *Qi* and *Qa* limits established in Clark Springs Wells right (G1-7660-A) described below. This source of supply is not, however, subject to the instream flow limitations set for the Clark Springs Wells.

The Clark Springs Trench consists of an infiltration gallery that was installed within a trench excavated into the aquifer downstream of Clark Springs. The collection system was constructed in 1957 and allows the collection of groundwater from an approximate depth of 10 to 20 feet.

### *Rock Creek Surface Water Diversion—Certificate No. 7232-A (Supplemental)*

Rock Creek Surface Water Diversion is a certificated, surface water source with an authorized primary instantaneous quantity *(Qi)* of 2,250 gpm (5 cfs). As a pre-1964 surface water right, no annual quantity limitation is assigned to the water right, although the City has established through beneficial use, an annual quantity *(Qa)* for this right in the amount of 3,600 af/yr which is supplemental to Clark Springs Well Right Certificate No. 7660. The Rock Creek water right has a priority date of 1931.

The right's purpose of use is for "domestic/municipal supply" and the designated place of use is the "City of Kent." The right was initially issued as a primary right and perfected as such. In 1969, the authorized *Qi* and *Qa* became subject to the limits established in Clark Springs Wells right (G1-7660-A) described below. This source of supply is not, however, subject to the instream flow limitations set for the Clark Springs Wells. The "intake structure" for this source is constructed as an extension of the infiltration gallery piping, and is a 12-inch-diameter steel pipe which extends under the Rock Creek channel to the southernmost side (Figure 21).

*Clark Springs Wells—Certificate No. 7660-A*

Clark Springs (Wells) is a certificated, primary groundwater source with an authorized instantaneous quantity *(Qi)* of 5,400 gpm (12 cfs), and an annual quantity *(Qa)* of 8,710 af/ft from three wells. The Clark Springs Wells water right has a priority date of 1969. The right's purpose of use is for "municipal purposes" the designated place of use is the "area served by City of Kent."

The three Clark Springs Wells are located in close proximity and within the same property as the City's Rock Creek and Clark Springs Trench Source, as described above. Each of the three wells is drilled and screened to an approximate depth of 30 to 60 feet, and tap the same Qvr aquifer that provides source to the Clark Springs Trench and discharges to Rock Creek. The wells have 16- to 18-inch-diameter casings and screens, and a combined production capacity of 5,400 gpm. The individual wells (numbered PW-1, PW-2, and PW-3 on Figure 21) have capacities of 900, 1,800, and 2,700 gpm, respectively.

Because of their hydraulic continuity with Rock Creek, the operation and beneficial use of the Clark Springs Wells is conditioned on ensuring the maintenance of the following instream flows: 15 cfs from January 1 to April 30; 15 cfs on May 1 decreasing arithmetically to 2 cfs by June 30, 2 cfs from July 1 through October 31, 15 cfs from November 1 through December 31. The Parshall Flume is installed in Rock Creek to continuously monitor flow conditions, as described in Section 3.3.3.

The City also has the means to discharge untreated water into Rock Creek from its pumping station at the CSWSS to ensure minimum instream flows are maintained during periods of pumping. To help meet these instream flow requirements when pumping the wells and as a part of the Rock Creek Resource Protection Plan, the City has installed an additional pump for streamflow augmentation at Clark Springs. This pump can divert up to 1,500 gpm from the CSWSS directly into Rock Creek, to augment streamflow by up to 3.3 cfs.

### 4.2.2 Water Supply Facilities

This section describes in more detail some of the infrastructure that comprises the CSWSS facilities within the Clark Springs Watershed. The infiltration gallery consists of perforated pipes laid perpendicular to the main direction of flow in Rock Creek (Figure 21). The pipework is laid with an invert level of 548 feet MSL, which is approximately 12 feet below the typical "static" groundwater level of 560 feet MSL. The main gallery consists of 270 feet of 16-inch-diameter perforated pipe (slotted well casing) laid in a bed of gravel. Aquifer materials in

the vicinity of the gallery are believed to be highly permeable sands, gravels, and cobbles.

Water from the gallery flows by gravity into the transmission main via a buried vault structure known as the Clear Well (Figure 21). The driving force being the hydraulic head in the gallery system, as reflected by the depth of water in the Clear Well. Although only limited construction details are available, it appears that the gallery pipework has ample open area for the amount of water intake under normal gravity conditions. The intake velocity through the gallery screen is estimated to be around 0.1 fps, which is generally accepted to induce minimal head loses as water enters the gallery from the aquifer. The head in the clear well is therefore probably only slightly lower (by a few tenths of a foot) than the average groundwater level immediately above the main gallery.

The system flows steadily under gravity at a rate of around 3,000 ±500 gpm (between 6.7 and 8.9 cfs). Changes in flowrate are driven by operational fluctuations in the transmission line back pressure and by changes in groundwater level. There is a seasonal change in groundwater level at the gallery of up to 5 feet. Higher gravity flows are typically recorded during the winter, when a higher driving head is available at the gallery.

The transmission pipeline from Clark Springs has a capacity of about 3,700 gpm (8.2 cfs) under gravity flow (URS 1985). and a full storage reservoir (designated GM #1) in the City of Kent. These conditions apply when the gallery is flowing by gravity and the well pumps are not operating. During the summer months, additional downstream inputs to the transmission line (from Soos Creek Well and Armstrong Springs) reduce the gravity-flow capacity from Clark Springs to between 2,900 and 3,400 gpm (6.5 and 7.6 cfs).

Under pumping conditions, the transmission pipeline from Clark Springs has a capacity of about 5,400 gpm (12 cfs) with an applied head of around 170 feet (URS 1985). Pumping conditions only come into effect when the wells at Clark Springs are being used. Back-pressure from the well pumps causes a check-valve to close, reducing a portion of the gravity flow from the gallery into the transmission main soon after the well pumps are brought into operation.

### 4.2.3 Water Production

Data on water production at Clark Springs since 1984 are summarized as monthly average flowrates in Table 4. Daily data have been collected by the City since 1978, from flowmeters on each of the three wells, and a master flowmeter located on the main transmission pipeline that records either total flow from the wells or gravity flow from the infiltration gallery. These data show

an overall rate of extraction that averages 6.2 cfs through 1999 (Figure 22). In some years, the wells at Clark Springs have been used to provide a significant portion of water production but in other years, water production has been from the infiltration gallery.

Reductions in system flows during the summer months of 2000, 2001, and 2002 were implemented by the City to improve streamflows as part of the Rock Creek Resource Protection Program during severe drought conditions in the Rock Creek catchment, when precipitation was substantially below normal. During this period, the City performed extensive streamflow augmentation by pumping water from the infiltration gallery directly into the creek (via the Clear Well) to help sustain low flows in the creek.

### 4.2.4 Hydrogeologic Conditions

The hydrogeologic conditions within the Clark Springs Watershed govern the relationship between groundwater in the outwash aquifer and streamflow in the perennial reach of Rock Creek, as well as controlling the stream-aquifer response to operations of the CSWSS facilities. This section presents and discusses these hydrogeologic conditions based on the field data and observations, the analysis of streamflow measurements, and the results of the modeling tasks.

#### *Baseflow Discharge at Clark Springs*

Rock Creek within the Clark Springs Watershed acts as a gaining reach year-round, with perennial flow in the creek sustained from here to the Cedar River confluence. Flow is maintained primarily through the natural discharge of groundwater as baseflow from the recessional outwash aquifer that extends upstream into the upper Rock Creek catchment. The quantity of baseflow discharge occurring is important to understand because it represents the groundwater flow within the system that sustains low-flow conditions in Rock Creek during the summer. It is also important to consider the (larger) volume of groundwater flow occurring in the aquifer, because this constitutes the water resource that the CSWSS draws upon. Only a portion of the total groundwater flow in the aquifer becomes baseflow in the creek; the remainder flows through the watershed within the aquifer.

Streamflow data from USGS gaging stations established for a short period at either end of the watershed and further downstream in the 1950s provide an indication of the variable baseflow contribution that is maintained throughout the year (see Figure 23). The data on this figure were generated by averaging the daily flows recorded downstream of Clark Springs at gages 12118400 and 12118500 during WY 1954-55, and subtracting from them the flows recorded at

Gage 12118300 immediately upstream of the watershed (see Section 3.3.3). The reduced data remove the effect of peak flows that are likely derived mainly from surface water runoff, showing a baseflow contribution that varies between 5 and 8 cfs into the winter, falling as low as 3 cfs by the summer of 1955.

### *Aquifer Configuration*

The shallow aquifer is composed of recessional deposits that range from fine sands and silts, which are poorly permeable, to gravels and cobbles that often occur in old glacial melt-water channels. The existing valley that carries Rock Creek above Clark Springs has the features of such a channel. Much of the groundwater flow is likely conducted into the valley via a subsurface glacial channel that acts as a drainage conduit for outflow from the main recharge area for the aquifer to the east.

The glacial outwash aquifer channel appears to be narrow or shallow (or both) in the area a few hundred feet upstream of Clark Springs. The hills to the north and south of the springs are of bedrock, capped with a veneer of glacial till. It appears that the central part of the valley east of Clark Springs conceals a buried ledge or saddle of till with perhaps shallow bedrock beneath.

Most of the aquifer flow entering the channel from the east appears to be forced to the surface, discharging from the aquifer as baseflow in the central part of the watershed to form surface flow in Rock Creek. As a result, there is less groundwater flow remaining in the aquifer, compared to the flow volume entering the watershed at the head of the valley.

Streamflow in Rock Creek develops as baseflow discharge from the subsurface glacial channel, which becomes constricted as it enters the small valley created by till-covered hills to the north and south of Kent-Kangley Road. Glacial till is recorded at a shallow depth below the channel floor near the CSWSS (Robertson & Anderson 1957) and may extend into the central portion of the valley. This subsurface ridge likely forces groundwater to the surface, sustaining flow in Rock Creek from this point westwards.

In the summer, flow volumes and groundwater levels in the aquifer are low, and the headwaters of Rock Creek are typically located a few hundred feet east of Clark Springs. Even in the driest years, however, flow still forms in Rock Creek at the eastern end of Clark Springs property, typically at least 1 mile upstream of the extraction facilities.

In the winter, flow volumes in the recessional aquifer are greater, and groundwater levels in the upgradient glacial channel are higher. This leads to flow in Rock Creek occurring further east.

### 4.2.5 2001 Infiltration Gallery Test

As part of the hydrogeologic investigations of Rock Creek, Hart Crowser conducted a monitored field test on the CSWSS Infiltration Gallery. The test consisted of cycling the operation of the infiltration gallery while recording groundwater elevations in select monitoring wells and creek stage upstream and downstream of the extraction facility. The purpose of the test was to analyze the drawdown and recovery of groundwater levels in the aquifer surrounding the infiltration gallery, to quantitatively determine the degree of hydrogeologic connection that exists between the aquifer and Rock Creek, and to measure the amount of baseflow capture that occurs when the infiltration gallery is operated during median flow conditions in the creek.

#### *Testing Method*

Seven of the existing monitoring wells at Clark Springs (DH-6, MW-1, MW-2, OBS 1, OBS 2, OBS 4, and PW) were monitored during the period May 7 through 10, 2001 (see Figure 21), when the flow in the creek was around 14 cfs. Both nested piezometers in OBS 2 were monitored, while only the deep piezometer in OBS 1 was monitored. In addition, the water levels in the Clear Well (CW) located within the CSWSS facility were recorded as this is taken to represent the water level within the infiltration gallery.

Creek stage was recorded at two locations: the Clark Springs Parshall Flume and gaging location HC-7, immediately adjacent to OBS 1 (Figure 21). The City's established Parshall flume equation was used to convert creek stage to flow at the flume.

Water levels were continuously monitored throughout the duration of the test using down-well MiniTroll (Insitu, Inc) pressure transducers. Before installation, manual depth-to-water measurements were made to establish a test datum. Similarly, river stage at the flume and the upstream monitoring location were recorded.

Following the installation of pressure transducers, the test period was initiated by the City of Kent's Public Works staff by first shutting off flow from the gallery, which had been operating normally prior to the test period. The first 12-hour period of no flow from the gallery was included to allow water levels to recover toward "natural" conditions. Following this monitored recovery period, flow

from the gallery was initiated for a period of around 12 hours, and then shut off again.

The 12-hour sequence of cycling the infiltration gallery flow on and then off was repeated while monitoring the observation wells and Rock Creek to allow for temporal analysis of the hydrologic response in both the aquifer and the creek. While operating, the infiltration gallery extracted water from the aquifer at approximately 3,300 gpm (7.35 cfs); the drawdown effect this created was measured in the monitoring wells. During system shutdown, no water was extracted from the aquifer, and the system was monitored for recovery of water levels.

### *Results*

Hydrographs for each monitoring location are provided on Figure 24. Hydrographs depict groundwater elevation versus time for the monitoring wells, head versus time for the Clear Well, and flow versus time for Rock Creek at the flume and at the manual measurement cross section HC-7 (located approximately 500 feet upstream of the CSWSS). Each monitoring well hydrograph shows a clear and well-defined cyclic pattern of variation that matches the on-off operation of the infiltration gallery, demonstrating the primary hydrologic response to flow in the gallery occurs within the body of groundwater contained in the aquifer at the CSWSS.

The response observed in Rock Creek in the form of changing water level at the flume reflects the capture of a portion of the baseflow (i.e., baseflow that would otherwise have discharged from the aquifer into Rock Creek) when the infiltration gallery was operating. The change in flow in Rock Creek does not occur in step-wise fashion but increases gradually as the increasing drawdown in the aquifer reduces the groundwater head that is driving the baseflow discharge. The recovery of flow in the creak is equally gradual following shut-off of the infiltration gallery.

The hydrograph for the upstream monitoring location shows that the depth of flow in Rock Creek at this location varied by a barely measurable amount (±0.01 foot), which translates to varying flowrates in the stream of between 5.2 and 5.4 cfs. These measurements provide direct evidence that the CSWSS facility operations have an insignificant impact on upstream flows in Rock Creek beyond a relatively short distance (i.e., less than 1,000 feet) from the facility. The finding is consistent with our understanding of the hydrogeologic conditions that created Clark Springs, with the analogy of flow occurring over a weir that effectively isolates the upper reaches of Rock Creek from any changes in streamflow that may occur due to operation of the CSWSS.

*Analysis*

Inspection of the hydrographs for the wells monitored shows a clearly defined cyclic drawdown response to extraction from the infiltration gallery. Drawdown in monitored wells range from 0.54 to 4.12 feet in OBS 1 and MW-1, respectively. A strong correlation between distance from the infiltration gallery versus drawdown is illustrated on Figure 25. The correlation is consistent with a one dimensional linear flow regime within the outwash aquifer contained in the channel approaching the infiltration gallery.

With the infiltration gallery located across the relatively narrow outwash channel, groundwater generally flows straight toward the gallery, with little or no component of radial convergence. This increase in the hydraulic gradient for flow approaching the gallery, as calculated by the best-fit trend line, is 0.0051 foot/foot. When there is no flow from the gallery, the hydraulic gradient is around 0.0045 foot/foot.

Recoveries of groundwater levels in the monitoring wells are as rapid as the drawdown. However, in neither case (during extraction or recovery) does the system reach equilibrium or steady state. Extrapolation of the drawdown and recovery trends suggests that steady conditions would be approached after 24 to 36 hours of continuous flow from the gallery.

The hydrograph for Rock Creek at the flume is presented on Figure 26a and analyzed to determine the degree of streamflow depletion associated with operation of the infiltration gallery under the prevailing test conditions.

The first stage of the analysis was to estimate the change in streamflow during a flow period for the infiltration gallery. A trend analysis was preformed on the initial rising limb of the hydrograph to extrapolate the probable recovery in streamflow toward steady state conditions with no flow from the gallery. The observed reduction in streamflow during the first stage of the test was then subtracted from this extrapolated trend to yield the amount of stream depletion (in cfs) caused by extracting water through the infiltration gallery (see Figure 26a).

The degree of streamflow depletion increases from zero at the time that gallery flow began, reaching around 85 percent of the gallery flow rate by the end of the 12-hour flow cycle. In this context, depletion in streamflow is measured as the amount by which streamflow is reduced (in cfs), divided by the constant flowrate from the infiltration gallery (7.35 cfs). Analysis of this graph to average out the transient response indicates that operation of the infiltration gallery captured approximately 65 percent of the total baseflow that would have

otherwise discharged from the aquifer entered Rock Creek by the end of the first 12-hour flow cycle. The total capture percentage along with the capture efficiency will rise as the duration of flow from the infiltration gallery lengthens.

A method for performing a hydrogeologic analysis of streamflow depletion (Hunt et al. 2001) was applied to the data to establish values for the aquifer parameters (transmissivity and storativity) and streambed leakance for Rock Creek. The method involves a graphical curve-matching procedure, with the observed drawdown and flow data compared to an empirical solution of drawdown and streamflow depletion caused by a pumped well located near a creek or river.

The conditions for the analysis are only approximately analogous to the system test conducted at Clark Springs, however. The method could not be applied in full because of significant differences in aquifer conditions. The Hunt analysis requires an assumption of an infinite lateral aquifer, unlike the tightly bounded Rock Creek channel. Also, in the theoretical model, pumping is from a well that represents a point sink in the aquifer, whereas the infiltration gallery strictly represents a line sink in hydraulic terms.

Figure 26b presents a qualitative comparison of the observed data with a type curve selected from the Hunt procedure. The type curve on the graph represents the theoretical maximum stream depletion for an unbounded aquifer with an ideal hydraulic connection to a neighboring stream (i.e., high streambed leakance). Also presented on the graph is the streamflow depletion (discussed above) measured in Rock Creek during the infiltration gallery test. The data from Rock Creek plot above the type curve. This indicates that extraction from the infiltration gallery has an exaggerated effect on Rock Creek — probably due to a an effective hydraulic connection between the outwash aquifer and Rock Creek, combined with the hydraulic barrier effects caused by the close proximity of the valley walls that tightly bound the aquifer. These conditions would tend to magnify the drawdown that is occurring in the aquifer and increase the degree of streamflow depletion, when compared to the unbounded aquifer system represented by the type curve.

Note that at the end of the 12-hour flow period the relative stream depletion (capture efficiency) was in excess of 86 percent and still rising. Extrapolating the trend of the type curve on Figure 26b, we estimate that 90 percent streamflow depletion would occur after around 1,100 minutes (18 hours) of continuous steady flow from the gallery. 95 percent streamflow depletion would occur after around 2,150 minutes (36 hours).

### *Conclusions*

The infiltration gallery test demonstrated the hydraulic connection that exists between the aquifer and Rock Creek and allowed us to estimate the amount of baseflow capture that occurs when the infiltration gallery is operated during median flow conditions in the creek. The results also demonstrate the dynamic conditions of flow and the transient variations that occur to both the groundwater system and the flow in Rock Creek when the CSWSS is operating.

In practice, steady flow conditions in a natural system such as Rock Creek or in the operation of the infiltration gallery do not last for any appreciable length of time. Each time there is a change in flow conditions, the hydrogeologic system readjusts after the manner of Figure 26b. A typical frequency for such flow changes is on the order of 12 to 24 hours, thus it can be concluded from our qualitative analysis of the test that a reasonable average value for the streamflow depletion attributable to the operation of the infiltration gallery under median streamflow conditions at Clark Springs is around 90 percent.

It should be noted that the hydrogeologic relationship between the creek and the aquifer is likely to be dependent on the overall flowrate of the creek and corresponding water levels in the aquifer. The conclusion presented above may apply at the level of streamflow at which the test was conducted (8 to 14 cfs), whereas differing degrees of streamflow depletion may apply at other flow rates (either higher or lower).

At high streamflow conditions, when the water table in the aquifer is also high, the degree of streamflow depletion would be expected to approach 100 percent because the aquifer will be full to capacity, with all the diverted flow coming from baseflow capture that would otherwise discharge to the creek. These results likely do not apply for low-flow conditions, when lower groundwater levels in the aquifer mean that a smaller proportion of the groundwater flow is discharged as baseflow, and increasing drawdown around the infiltration gallery could lower aquifer levels below the bed of the creek.

The Modflow model of the Rock Creek system (Appendix H of the Clark Springs BA) was used to simulate the test on the infiltration gallery and then apply the results to high and low conditions of groundwater flow simulated in the model. However, repeated tests of the infiltration gallery at substantially different flow conditions would be required to better define the overall hydrogeologic relationship between the operations at Clark Springs and flow in Rock Creek under other flow régimes (e.g., low-flow or flood flow).

### 4.2.6 1997 Well Pumping Test

The City has conducted earlier production tests of the CSWSS. One test in 1997 focused on the effect of pumping the three wells installed at the CSWSS, with no flow occurring from the infiltration gallery. This section of the report presents the results and analysis of the 1997 test to show the similarities and differences in groundwater and streamflow responses observed when water supply operations utilize the wells at the CSWSS to provide water supply for the City.

#### *Testing Method*

Three production wells were installed at Clark Springs in 1968, following the drilling of pilot or test holes, which proved the presence of a lower sand and gravel aquifer that exhibited good water supply potential. Two of the test holes remain (adjacent to Wells 1 and 2) and are used now to monitor groundwater levels.

The production wells are located in a line parallel to the main infiltration gallery, but offset downstream by about 140 feet (see Figure 21). In December 1997, Hart Crowser assisted the City of Kent Public Works staff in performing and monitoring a controlled test of the production wells. The test involved pumping the three wells for a period of approximately 2 days, while monitoring drawdowns in various monitoring wells at the CSWSS facility.

#### *Results*

A summary of the observed test responses is shown on Figure 27, which includes graphs showing the total pumping rate from the wells of around 4,500 gpm (10 cfs), and data on the flow in Rock Creek from both the Clark Springs Flume and King County Gage 31L. The impact of well pumping on Rock Creek is evidenced by a reduction in streamflow of around 7 cfs (Figure 27a), while substantial drawdowns of around 25 feet or more occurred in the aquifer around the wells (Figure 27b).

The large drawdowns (relative to the operational characteristics of the infiltration gallery) reflect the difference in facility construction, with the vertical wells concentrating the drawdown locally, whereas the horizontal infiltration gallery distributes the drawdown over a wider area. Also, the well drawdown may be further amplified by the highly bounded aquifer system that supplies water to the pumping wells. The narrow bedrock channel has side walls composed of low-permeability bedrock that creates hydraulic barriers to lateral flow, constricting flow in the valley sediments. Also, there may be a partial barrier to groundwater flow both upstream and downstream of rock creek (e.g., buried rock ledges;

high spots formed of glacial till). These factors likely increase the drawdown effect created by well pumping.

As drawdowns increased progressively through the test, well interference effects forced a slight reduction in well pumping rates, such that the total pumping rate at the end of the test dropped slightly to around 4,250 gpm (9.5 cfs).

### *Analysis*

Based on a comparison between the discharge rate from the wells (10 cfs) and the observed reduction in streamflow (7.1 cfs), the streamflow depletion estimated from this test appeared to represent around 70 percent of the total pumping rate from the wells. The lower streamflow depletion compared to the infiltration gallery reflects the greater degree of groundwater storage depletion, which is manifested by large drawdowns in the aquifer. The test appeared to reach quasi-equilibrium conditions after about 1,000 minutes, despite drawdown in the aquifer continuing to increase.

Also, the streamflow did not start to recover immediately after the wells were turned off. Rather, stream flowrates remained depleted for a number of hours, until water levels in the underlying aquifer had recovered toward the elevation of the creek (see Figure 27). Streamflow then continued to recover over the next 12 hours until it was within 1 cfs of the flowrate at the start of the test.

Taking into account the delayed recovery of streamflow after the wells were turned off, the total volume of water depleted from the stream over the full duration of the period of impact is calculated to be around 90 percent of the total volume pumped from the three wells. The difference in the estimated amount of depletion occurs because this second method considers the amount of water that is removed from storage within the aquifer as the drawdown occurs, and the recovery of this water into storage underground as groundwater levels recover.

### *Conclusions*

In summary, the aquifer system at Clark Springs acts in part like an underground storage reservoir of limited volume, with only component of groundwater through-flow. When the wells are not being used, the reservoir is generally full and part of the groundwater through-flow is diverted by the infiltration gallery. When the gallery is turned off, a portion of the groundwater that would have entered the gallery now discharges to Rock Creek.

When the well pumps are turned on, they start to draw the water that was flowing to the gallery; they also draw in water stored within the underlying aquifer. Additional pumping of the laterally bounded groundwater reservoir hastens the rate at which the stored water is depleted, causing progressively increasing drawdowns observed in the 1997 test. Under operational conditions, well flows vary with water demand and other factors determined by the City's supply system, such that sustained flow can be obtained with stabilized well drawdowns.

### 4.2.7 Streamflow Augmentation

The system tests at the CSWSS facilities provide valuable data about the degree to which streamflows are depleted by water supply operations; however, there is evidence when reviewing the current partial records of streamflow and water production that the proportion or amount of streamflow depletion is not constant, but varies with differing flow rates and is likely strongly influenced by prevailing water levels in the aquifer.

More work is needed to characterize the range of streamflow depletion that occurs, particularly at low flows in the range of 2, 3, or 4 cfs, which are critical in the late summer periods. Additionally, the City has been performing streamflow augmentation by diverting to the creek a portion of the water that is extracted from the aquifer by the infiltration gallery. A field test of this system is needed to quantify the net benefit in terms of streamflow maintained in the downstream reach.

From the data collected and interpreted to date, it appears that augmentation at low flows diverts groundwater flow into the creek that would otherwise bypass the creek and remain as groundwater through-flow in the underlying aquifer. This is one explanation for the net increase in streamflows seen when the augmentation system is operating.

The beneficial effects of augmentation also appear to be aided by the inferred presence of low-permeability sediments forming the bed of Rock Creek from Clark Springs downstream. The low-permeability streambed appears to act as perching layer that retains streamflow and makes it difficult for significant stream losses to occur as infiltration, even when the ambient groundwater levels drop below the bed of the creek. This complex hydrogeologic phenomenon is discussed in more detail in the Modflow Study Report included as Appendix F of the Clark Springs BA.

## *4.3 Lower Rock Creek — Perennial Stream*

Downstream of the facilities area at Clark Springs, Rock Creek continues to flow north, rather than following a westward course that might be expected from other regional drainage patterns. This may be attributed to the inferred presence of a shallow bedrock structure beneath the surface west of Clark Springs, which likely directs flow northward along the path of a pre-existing drainage channel eroded into the bedrock.

As a result, the extension of the aquifer to the west beyond the Clark Springs property may be limited by shallow bedrock and till. A limited amount of groundwater remains as underflow in the aquifer and moves to the west from the Clark Springs area following the regional flow regime.

The course of the creek north of Clark Springs passes through a weakly incised valley cut through the recessional outwash that blankets the area. The creek includes relatively flat wetland reaches that appear to be underlain by glacial till. Interpretation of local well logs suggests that groundwater in this area occurs primarily in the advance outwash underlying the till, with limited aquifer development in the recessional outwash above the till that forms the valley flanks throughout this reach. In this area, groundwater levels tend to be generally lower that adjacent creek levels (Figure 10).

The catchment for the creek in this area is relatively small and lacks the area to generate substantial groundwater flow. Runoff from hills to the south likely infiltrates the recessional outwash with much of the groundwater flowing to the north and directly discharging to the Cedar River, rather than entering Rock Creek. Gains in creek flow are therefore limited to periods of heavy precipitation when some runoff from the catchment finds its way to the creek.

Losses in creek flow over this reach also appear to be limited by the nature of the streambed and/or underlying soils directly beneath the streambed. Densely compacted glacial till in the upper parts of the reach provides a low-permeability substrate for the creek, changing to dense advance outwash or older glacial sediments of similarly low permeability in the lower part of the reach, above the Cedar River floodplain.

The geological and topographic conditions in the lower combine therefore combine to limit both gains and losses to the creek. For most of the year, streamflow leaving Clark Springs provides almost all of the flow running through the lower reach to discharge into the Cedar River at the mouth (see Figure 14c).

# 5.0 MANAGEMENT STRATEGIES

This section presents an overview of potential management strategies that could be considered by the City by way of mitigation for perceived impacts to streamflow in Rock Creek.

## *5.1 Watershed Controls*

The analysis presented above confirms that flows in the perennial lower reach of Rock Creek are substantially influenced by a range of conditions pertaining to the upper Rock Creek valley plain. The abundance of water in any given year depends primarily on the amount of precipitation (rainfall and snowmelt) in the upper valley and surrounding hills. The infiltration of that water to recharge the underlying aquifer is controlled in part by land use, especially development that increases the amount of impervious surfaces in the catchment.

In most Puget Sound catchments, impervious surfaces traditionally develop surface runoff that contributes directly to increased streamflow, raising storm peaks and reducing the amount of water stored in the soil or percolating down to recharge the groundwater. However, in the upper Rock Creek valley plain, increased runoff from impervious surfaces generally flows onto the highly permeable surrounding soils, thus increasing the amount of infiltration and groundwater recharge.

Development within the catchment also has a potential impact on water quality; surface runoff carries increased contamination load, which may not be effectively filtered as it percolates through the coarse-grained highly permeable outwash soils. Also there is no sewerage service so all used water returns as septic outflows that percolate down to the shallow body of groundwater. The removal of trees and pasture vegetation, and its replacement with lawns and landscaped plantings potentially increases the load of pesticides and nitrates entering the groundwater system.

Controls on development can be difficult to legislate, and must be applied at the city and county level. Sufficient instruments exist within the county; for example, the entire floor of the upper valley plain, and even the flanks of the surrounding hills, could be justifiably designated a Critical Aquifer Recharge Area under the County's Sensitive Areas Ordinance. This could allow more stringent controls on development, with improved Best Management Practices required that addressed the specific problems identified above, which will have an increasing impact on the amount and quality of water available to sustain flows in Lower Rock Creek.

## 5.2 Clark Springs Operations

Controlled tests of the City's water supply facilities at Clark Springs have shown that there is only a relatively short delay before the withdrawal of groundwater via the infiltration gallery or the wells begins to significantly impact flows in Rock Creek at the prevailing median streamflows. After approximately 12 hours of withdrawal, around 90 percent of the derived groundwater flow is capturing baseflow that would otherwise discharge from the aquifer and contribute to flow in the Creek.

From an operational perspective, streamflow in the creek can therefore be increased by scaling back the rate at which groundwater is withdrawn for water supply purposes. This strategy could potentially be implemented at times when creek flows are low. The strategy would likely require the City to utilize alternative supplies to meet current demand and provide adequate fire-flow protection. The viability of this management strategy as a means for reducing potential take depends largely on the City's ability to substitute other sources in place of Clark Springs.

## 5.3 Streamflow Augmentation

The City has practiced streamflow augmentation at Clark Springs over the last few years. This has restored between 1 and 3 cfs of lost flow at critical periods, especially when recorded flows have dropped below 2 to 3 cfs.

Continued use of streamflow augmentation by pumping some flow back into the creek from the Clear Well at the Clark Springs will provide a flexible and responsive approach to mitigating low flows at critical periods.

A significant advantage of streamflow augmentation at low-flow periods is that a significant proportion of the augmentation flow comes not from baseflow capture but from groundwater through-flow in the aquifer that would not have entered the creek. Also, once water is flowing in the creek at Clark Springs, there appears to be relatively little if any loss of flow to groundwater, even though groundwater levels may be depressed below the base of the creek. This finding should be confirmed by repeating the monitored tests of the CSWSS facilities at low streamflow conditions, with and without augmentation, while the operation of the infiltration gallery is cycled on and off.

Other possibilities for streamflow augmentation have been considered. These include:

- Pumping back groundwater that is flowing west of Clark Springs;

- Diverting some flow from the Cedar River and piping this up to Clark Springs;
- Intercepting groundwater flow that leaves the basin via Ravensdale;
- Capturing groundwater lost from the northeast portion of the upper basin, north of the town of Kangley; and/or
- Storing winter stream flow upstream of Clark Springs by ponding; allowing it to infiltrate into groundwater at a controlled rate.

The brief discussions below focus on the technical feasibility of possible streamflow augmentation schemes; little consideration is given at this time to the primary issue of significance in such schemes—the acquisition of water rights.

### 5.3.1 Groundwater Pump-Back

The City investigated the possibility that groundwater at the western end of the Clark Springs Watershed could be pumped back to augment flows in Rock Creek. A test well was drilled at the western end of the property but the aquifer at this location proved to have insufficient yield for an augmentation scheme. Water rights could have also been an issue as pumping from this location would draw on the water resources of the Soos Creek Basin.

### 5.3.2 Diversion from the Cedar River

The City has looked into the possibility and likely cost of pumping water from the Cedar River, via a pipeline up to Clark Springs. The advantage of the scheme would be that flow could be diverted a short way upstream of the Rock Creek confluence and would return as flow in the creek, with minimal impact on flows in the Cedar River or any other existing water rights. Apart from the substantial capital and operating cost, the question of water quality is one of the major obstacles, since this would introduce surface water, rather than groundwater into the creek at Clark Springs. The water temperature and oxygenation of the natural stream would be somewhat affected.

### 5.3.3 Groundwater Interception at Ravensdale

A substantial portion of groundwater flow – estimated by Modflow groundwater modeling (see Appendix H) to be between 5 and 8 cfs – is lost from the upper Rock Creek catchment as it discharges though the glacial outwash channel at Ravensdale. Some of this groundwater flow could be captured by installing a well near Ravensdale and piping the flow a short distance to the northwest, to discharge into Rock Creek within the Clark Springs Watershed. In this way, the drawdown effect of the pumping well should have negligible effect on the rate

of natural groundwater flow into the Clark Springs Watershed that becomes baseflow discharge to Rock Creek.

### 5.3.4 Groundwater Capture North of Kangley

There is a body of groundwater within the upper Rock Creek catchment that is isolated from the main part of the aquifer system sustaining flow in Rock Creek. Groundwater north of the Kangley and the Kent-Kangley sand and gravel pit cannot flow to the west or discharge to Rock Creek because of a buried bedrock ridge that appears to form a hydraulic barrier to subsurface flow at this location. Groundwater appears to flow north or northwest, discharging to the Cedar River.

The aquifer in this area is extremely permeable, and receives copious recharge as the orographic effect of the hills to the east starts to take effect on precipitation patterns. One or more wells in this location could likely generate substantial groundwater flows that could be provided for augmentation of flow in Rock Creek. Water could be piped to Clark Springs Watershed, a distance of around 5½ miles.

Alternatively, to save in pipeline costs, water could be piped a shorter distance to recharge the Rock Creek aquifer in a closer location, for example, the shooting park west of the Evergreen Acres subdivision. However, a portion of the amount pumped would be lost from the basin, and would not report as baseflow discharge to Clark Springs.

## 6.0 CONCLUSIONS

1. Rock Creek forms a unique complex hydrologic system in which the perennial streamflow in the lower reach is attributed to the recharge, storage, and release of groundwater from an extensive aquifer underlying the upper valley plain east of Ravensdale. Recharge is a combination of direct infiltration through highly permeable glacial soils, and runoff/interflow from the till-mantled bedrock hills that ring the upper valley plain.

2. Surface flow in the upper Rock Creek reaches is intermittent, dictated by wetter months and heavy precipitation events, rapid infiltration creating high water tables that can cause saturation and flooding of the otherwise highly permeable glacial deposits. During dry periods, the water table typically does not rise high enough to generate sustained streamflow within the upper reaches of the creek (except at Lake Twelve).

3. Land use changes in the upper valley plain have the potential to change groundwater recharge and thus alter the amount of water available in the aquifer. This effect has been relatively small to date because the area remains relatively undeveloped, but increasing development in the future could alter the amount of groundwater recharge feeding the aquifer.

4. Some groundwater leaves the upper Rock Creek catchment to the southwest via the Ravensdale aquifer channel, and possibly also to the north via the Landsburg aquifer channel. These natural out-of-basin flows deplete the flows of groundwater available at Clark Springs. Based on our modeling studies, these flows may represent as much as half of the total groundwater flow in the upper Rock Creek catchment.

5. At Clark Springs, much of the groundwater flow from the upper valley plain is forced to discharge into the Rock Creek stream channel in the form of baseflow as the aquifer becomes restricted within a narrow bedrock valley.

6. Baseflow entering the creek at Clark Springs flows through the lower perennial reach with little gain or loss before discharging to the Cedar River between Landsburg and Maple Valley.

7. Water extracted at Clark Springs by the City comes directly from groundwater via wells or the infiltration gallery. Depending on creek flows and groundwater levels in the aquifer, a portion of the groundwater extracted is derived from the capture of baseflow – groundwater flow that would otherwise discharge from the aquifer into Rock Creek.

8. A portion of the groundwater remaining in the aquifer continues its regional flow westward to recharge the extensive outwash aquifer in Soos Creek Basin that feeds other sources such as the Witte wellfield and Kent Springs and Armstrong Springs.

9. A streamflow depletion factor of between 70 and 90 percent was determined at median flowrates in Rock Creek when the CSWSS facility is operating. Streamflow depletion is likely greater at higher flows, when there is less aquifer drawdown associated with the infiltration gallery extraction, the aquifer remains fully saturated, and all extracted flow is derived from baseflow that is potential streamflow. However, conditions at higher flows have not been determined by field testing.

10. Different conditions apply at lower flows, where the aquifer is not full to overflowing, and much of the (smaller) groundwater flow bypasses the creek, but can be tapped by the infiltration gallery or the wells at the CSWSS

with much less impact on baseflow capture. Under these low-flow conditions, the streamflow depletion appears to be significantly less than observed at median streamflows. Additional field monitoring tests of the system are required at low flows to quantify this effect.

11. Streamflow augmentation by pumping from the Clear Well at the Clark Springs facility diverts a portion of the groundwater through-flow from the aquifer into the creek (up to 3 cfs when operating). The added flow appears to remain in the lower reach (rather than being lost to groundwater) and discharges to the Cedar River.

12. Streamflow augmentation from sources outside of Rock Creek catchment would result in a corresponding net increase in streamflow. However, this would likely invoke difficult water rights issues.

13. Streamflow augmentation from sources (e.g., wells in the upper valley plain) upstream of Clark Springs will have a reduced effect on baseflow capture at Clark Springs since the wells would intercept a portion of groundwater flow that is currently lost from Rock Creek catchment through the Ravensdale aquifer channel. However, such interception would potentially reduce westward regional groundwater flow that recharges aquifers in the Soos Creek Basin.

## 7.0 REFERENCES


Brown & Caldwell 1980. Cedar River Well Field Study, Phase II; Final Report prepared for Seattle Water Department, March 15, 1980.

Ecology 2003. Water Resource Inventory (WRIA) Maps. Washington State Department of Ecology Website, URL: http://www.ecy.wa.gov/services/gis/maps/wria/wria.htm

GeoEngineers 2000. A Hydrology Evaluation for the Boundary Line Adjustment, Ravensdale, Washington, prepared for the Jack McCann Company.

Hart Crowser 1996. Wellhead Protection Program for the City of Kent and their Clark, Kent, and Armstrong Spring Facilities.

Hunt, B., J. Weir, and B. Clausen 2001. A Stream Depletion Field Experiment. Ground Water Vol. 39, No. 2, pp 283-289.

Luzier, J.E. 1969. Geologic Map of Southwestern King County, Washington Department of Water Resources, State of Washington.

King County (King County Department of Public Works) 1993. Cedar River Current and Future Conditions Report. King County Department of Public Works Surface Water Management Division, Seattle, Washington.

King County 1987. Draft Environmental Impact Statement, Kangley Site Sand and Gravel Operation, Proposed Rezone. May 1987.

Oregon Climate Service 1997. Mean Annual Precipitation Maps for Western United States, PRISM Model, Corvallis, Oregon.

Ritter D.F, R.C. Kochel, and J.R., Miller 1995. Process Geomorphology: Boston, William C. Brown, 546 pp.

Robertson, F., and K.E. Anderson 1957. Geology and Ground Water Resources in Glacial Stream Channel of Rock Creek, King County, Washington. Report prepared for the City of Kent, Washington; August 30, 1957.

Robinson & Noble, Inc. 1995. Wellhead Protection Plan for the Covington Water District.

SKCGWMP 1991. A Groundwater Management Plan (GWMP) for South King County, Prepared under grants from the Washington State Department of Ecology.

Sumioka, S.S., D.L. Kresch, and K.D. Kasnik 1997. Magnitude and Frequency of Floods in Washington. US Geological Survey Water Resources Investigations Report 97-4277, Tacoma, Washington.

URS Corporation 1985. Clark Springs Source Improvements Feasibility Report. Prepared for the City of Kent, November 22, 1985.

USGS 2003. Real-time data for USGS 12118400 ROCK CREEK AT HIGHWAY 516 NEAR RAVENSDALE, WA. Internet Webpage, US Geological Survey Website, URL: http://waterdata.usgs.gov/wa/nwis/uv?12118400

Vine, J. D. 1969. Geology and coal resources of the Cumberland, Hobart, and Maple Valley quadrangles, King County, Washington. US Geological Survey Professional Paper 624, 67 pp.

Walsh, Timothy J. 1984. Geology and Coal Resources of Central King County, Washington by Department of Natural Resources, State of Washington.

WRCC 2002. Evaporation Table for the Western States. Western Regional Climate Center, Desert Research Institute Website, URL: http://www.wrcc.dri.edu/htmlfiles/westevap.final.html

Williams, R.W., R.M. Laramie, and J.J. Ames 1975. A Catalog of Washington Streams and Salmon Utilization. Volume 1. Puget Sound Region. Washington State Department of Fisheries, Olympia.

Wolcott, E.E., Washington State Water Program. 1973. Lakes of Washington, Water Supply Bulletin No. 14, Volume 1.

F:\Docs\JOBS\747006\Hydrogeology\Hydrogeology Report.doc

## Table 1 - Manual Streamflow Measurements

| Station ID | Station Description | Date of Measurement | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 9/25/2000 | 9/26/2000 | 9/28/2000 | 10/3/2000 | 10/18/2000 | 11/10/2000 | 12/28/2000 | 1/25/2001 | 3/28/2001 | 4/5/2001 | 4/10/2001 |
| HC-1 | Rock Creek Mouth | | 1.66 | | 6.16 | 6.44 | 5.54 | 6.67 | | | | |
| HC-2 | Rock Creek above SE 248th St. | 1.70 | | | 7.48 | 5.79 | 6.03 | 6.92 | | | | |
| HC-3 | Rock Creek above Seattle Pipeline | 1.73 | 2.44 | 3.53 | 6.37 | 5.52 | 4.46 | 7.03 | 9.4128 | | | |
| HC-4 | Rock Creek at Wilderness Park | | | | | | 4.58 | 5.64 | 6.80725 | | | |
| HC-5 | Rock Creek at Kent Pipeline | 1.59 | | | 6.76 | 6.34 | | | 5.3935 | | | |
| HC-6 | Rock Creek at Kent Flume | 1.60 | 3.29 | | 5.43 | 6.62 | | | 6.6834 | 4 | 5.98 | 8.64 |
| HC-7 | Rock Creek under T-Line | | | | | | | | 3.95475 | | | |
| HC-8 | Rock Creek at E. Watershed Bdy | | | | | | | | 1.823 | | | |
| HC-9 | 262 Avenue SE | | | | | | | | | 0 | 0.1 | 0.5 |
| HC-10 | Georgetown Creek at Kent-Kangley | | | | | | | | | 0 | 0 | 0.25 |
| HC-11 | 268 Avenue SE | | | | | | | | | 0 | 0 | 0 |
| HC-12 | Ravensday Way | | | | | | | | | 0 | 0.1 | 2.01 |
| HC-13 | RKCK13 | | | | | | | | | 0 | 0.34 | 1.73 |
| HC-14 | RKCK10 | | | | | | | | | 0 | 1.41 | 3.06 |
| HC-15 | RCNOFL | | | | | | | | | 0.23 | 2.04 | 3.38 |
| HC-16 | Plum Creek Wetland | | | | | | | | | 1.80 | 2.28 | 2.41 |
| HC-17 | Brathovde Culvert (RKCK08) | | | | | | | | | 3.26 | 8.30 | 8.88 |
| HC-18 | Lake 12 Outlet (290 Ave. SE) | | | | | | | | | 4.78 | 5.23 | 7.64 |

Flow measurements are in cfs

## Table 2 - DOH Well-Based Water Systems in Rock Creek Basin



| Key No. | Name | Group | Well Depth in Feet | Capacity in gpm | Quarter Section | Section | Township | Range | SRC_NAME |
|---|---|---|---|---|---|---|---|---|---|
| 0014601 | GREISING | B | 36 | 25 | SENW | 23 | 22 | 06E | GREISING |
| 0170301 | VANDERBERG/PETERSON | B | 129 | 2 | NENE | 32 | 22 | 07E | WELL |
| 0199001 | RAVENSDALE MARKET | B | 60 | 5 | SESE | 25 | 22 | 06E | WELL #1 |
| 0246401 | WAITE, D. | B | 160 | 34 | | 33 | 22 | 07E | |
| 0301401 | CRISTALINA WATER COMPANY | A | 139 | 70 | NWSW | 28 | 22 | 07E | WELL #1 (#27) |
| 0301402 | CRISTALINA WATER COMPANY | A | 125 | 45 | NWSW | 28 | 22 | 07E | WELL #2 |
| 0313901 | BLACKWATER CO-OP | B | 165 | 4 | SWNW | 32 | 22 | 07E | WELL #1 |
| 0313902 | BLACKWATER CO-OP | B | 360 | 20 | SWNW | 32 | 22 | 07E | WELL #2 |
| 0343901 | PICHININI | B | 73 | 999 | NENW | 32 | 22 | 07E | WELL #1 |
| 0396401 | WHITE, M. COMMUNITY W.S. | B | - | - | SWSW | 29 | 22 | 07E | WELL |
| 0402601 | JONES/SWANSON | B | 46 | 30 | NWNE | 32 | 22 | 07E | |
| 0539801 | PITTS, W. WATER SYSTEM | B | - | - | SWNW | 33 | 22 | 07E | WELL |
| 0618201 | HENRY COMMUNITY WS | B | - | - | NESE | 12 | 21 | 06E | WELL #1 |
| 0821501 | BREMMEYER,B WATER | B | 40 | 750 | NWNE | 32 | 22 | 07E | |
| 0884701 | WATER SYSTEM 305 | B | 89 | 39 | | 32 | 22 | 07E | WELL # 1 |
| 1000001 | BUTCHER, AC | B | 30 | 900 | NWNW | 26 | 22 | 06E | WELL #1 |
| 1223201 | BRIDLE TRAILS SOUTH WATER SYSTEM | A | 47 | 32 | SWSW | 25 | 22 | 06E | WELL #1 |
| 1223202 | BRIDLE TRAILS SOUTH WATER SYSTEM | A | 47 | 46 | SWSW | 25 | 22 | 06E | WELL #2 |
| 1223203 | BRIDLE TRAILS SOUTH WATER SYSTEM | A | 47 | 78 | SWSW | 25 | 22 | 06E | WELLS #1 & 2 |
| 1420101 | HARVEY, S. | B | 60 | 12 | | 32 | 22 | 07E | WELL # 1 |
| 2418001 | EVERGREEN WATER & IMPROVEMENT ASSN. | A | 150 | 75 | SWSE | 28 | 22 | 07E | WELL A |
| 2418002 | EVERGREEN WATER & IMPROVEMENT ASSN. | A | 300 | 60 | SWSE | 28 | 22 | 07E | WELL B |
| 2524601 | LAKE RETREAT FIRS NO 4 | B | 360 | 26 | | 32 | 22 | 07E | DRILLED WELL #2 |
| 2619901 | SUMMIT LANDSBURG HOUSES 1-4 | B | 163 | 30 | SWSW | 24 | 22 | 06E | WELL #1 |
| 2981701 | MARKUS, R.K. | B | 34 | 10 | | 32 | 22 | 07E | WELL NO. 1 |
| 3069001 | HAMILTON,J WATER | B | 10 | - | SWNE | 32 | 22 | 07E | |
| 3549001 | MARKUS, L. | B | 78 | 28 | | 30 | 22 | 07E | WELL |
| 3801101 | S.E. 258TH PL. WATER ASSOCIATION | B | 176 | 37 | | 30 | 22 | 07E | WELL |
| 3849101 | WHITEWATER | B | 137 | 28 | | 32 | 22 | 07E | WELL |
| 4165008 | COVINGTON WATER DISTRICT | A | 40 | 106 | NENE | 36 | 22 | 06E | RAVENSDALE-FD#43 |
| 4306601 | ASSOCIATED WATER SYSTEM #11 | B | 143 | 36 | SENE | 30 | 22 | 07E | WELL #1 |
| 4440005 | LAKE RETREAT CAMP & CONF CENTER | A | 90 | 7 | NESW | 32 | 22 | 07E | WELL #3 |
| 4441501 | LAKE RETREAT FIRS #1 | B | 105 | 40 | SESW | 32 | 22 | 07E | |
| 4441601 | LAKE RETREAT FIRS #2 WATER ASSOC. | A | 110 | 40 | SESW | 32 | 22 | 07E | LAKE RETREAT #2 WELL |
| 4443001 | LAKE RETREAT RIDGE | B | 220 | 6 | NWSE | 32 | 22 | 07E | |
| 4452101 | DUFFY WATER SYSTEM | B | 60 | 24 | SENW | 23 | 22 | 06E | WELL #1 |
| 4631601 | SUGARLOAF WATER SYSTEM | A | 540 | 30 | SWNE | 04 | 21 | 07E | JBA WELL #1 (EAST) |
| 4631602 | SUGARLOAF WATER SYSTEM | A | 440 | 75 | SWNE | 04 | 21 | 07E | JBA WELL #2 (WEST) |
| 4631603 | SUGARLOAF WATER SYSTEM | A | 440 | 105 | SWNE | 04 | 21 | 07E | JBA WELLS # 1,2 |

## Table 2 - DOH Well-Based Water Systems in Rock Creek Basin



| Key No. | Name | Group | Well Depth in Feet | Capacity in gpm | Quarter Section | Section | Township | Range | SRC_NAME |
|---|---|---|---|---|---|---|---|---|---|
| 4631604 | SUGARLOAF WATER SYSTEM | A | 160 | 200 | SENE | 05 | 21 | 07E | SUGARLOAF WELL #3 |
| 4758001 | LITRAS SPRING WATER SYSTEM | B | - | - | NENW | 32 | 22 | 07E | |
| 5034501 | MAIER / BRAZIER WATER SYSTEM | B | - | - | NENW | 08 | 21 | 07E | |
| 5227401 | M & M #1 | B | 114 | 22 | SWNE | 29 | 22 | 07E | WELL |
| 5542001 | MJELDE | B | 60 | 75 | NENE | 32 | 22 | 07E | |
| 5762101 | ASSOCIATED WATER #15 | B | 89 | 13 | NWSE | 30 | 22 | 07E | ASSOCIATED #15 |
| 7139701 | RAVENSDALE MOBILE HOME PARK | A | 41 | - | SESE | 25 | 22 | 06E | WELL # 1 |
| BP48001 | RAVER SUBSTATION | B | 138 | 25 | NESE | 04 | 21 | 07E | WELL |
| 4190001 | KING COUNTY WATER DISTRICT #111 | A | - | - | NESW | 26 | 22 | 06E | 381501/KENT |
| 6601201 | HOKENSON WATER SYSTEM | B | 185 | 12 | SESE | 22 | 22 | 06E | HOKENSON |
| 9714001 | WILLIAMS,R | B | 167 | 30 | SWNW | 04 | 21 | 07E | |
| 4507801 | LAKE WILDERNESS CO PARK | B | 11 | - | NESE | 22 | 22 | 06E | |
| | | | Total | 4,231 gpm | | | | | |

Data from Washington State Department of Health
Excludes City of Kent's Wells at Clark Springs

Table 3 - Water Rights in Rock Creek Basin

| Township/ Range - Section | ID Number | Type of Right | Purpose | Amount of Flow cfs | gpm | ac-ft | Units Served | Last Name | First Name | Business Name |
|---|---|---|---|---|---|---|---|---|---|---|
| T21N/R07E-03 | G1-23088CWRIS | CERTIFICATE | DM· | | 100 | 27 | | | | MARIANI WTR SYSTEM |
| T21N/R07E-04 | G1-018693CL | CLAIM/L | DG | | | | | CHAMBERS | WALTER A. | |
| T21N/R07E-04 | G1-056983CL | CLAIM/S | DG | | | | | MARKUS | JOSEPH P. | |
| T21N/R07E-04 | G1-069155CL | CLAIM/S | DG ST | | | | | HELDRETH | MAURICE | |
| T21N/R07E-04 | G1-069155CL | CLAIM/S | DG ST | | | | | HELDRETH | MAURICE | |
| T21N/R07E-04 | G1-084733CL | CLAIM/S | DG | | | | | MARKUS | STEVEN J. | |
| T21N/R07E-04 | G1-124732CL | CLAIM/L | DG | | | | | | | DAVENPORT HOWARD K |
| T21N/R07E-04 | G1-141914CL | CLAIM/L | DG | | | | | WILEY | HOWARD M | |
| T21N/R07E-04 | G1-148618CL | CLAIM/S | DG ST IR | | | | | WYATT | DAYLE D | |
| T21N/R07E-04 | G1-148618CL | CLAIM/S | DG ST IR | | | | | WYATT | DAYLE D | |
| T21N/R07E-04 | G1-148618CL | CLAIM/S | DG ST IR | | | | | WYATT | DAYLE D | |
| T21N/R07E-04 | G1-148752CL | CLAIM/S | DG ST IR | | | | | MEDALE | CHARLES L | |
| T21N/R07E-04 | G1-148752CL | CLAIM/S | DG ST IR | | | | | MEDALE | CHARLES L | |
| T21N/R07E-04 | G1-148752CL | CLAIM/S | DG ST IR | | | | | MEDALE | CHARLES L | |
| T21N/R07E-04 | G1-23873CWRIS | CERTIFICATE | DM· | | 8 | 4.5 | | | | LEMIEUX WTR SYSTEM |
| T21N/R07E-04 | G1-24994C | CERTIFICATE | DM· | | 71 | 42.56 | | | | ALCORN JAMES E |
| T21N/R07E-04 | G1-24994C | CERTIFICATE | DM· | | 71 | 42.56 | | | | ALCORN JAMES E |
| T21N/R07E-04 | S1-047098CL | CLAIM/S | DG ST | | | | | BALINT | MATHEW E | |
| T21N/R07E-04 | S1-047098CL | CLAIM/S | DG ST | | | | | BALINT | MATHEW E | |
| T21N/R07E-05 | G1-*08743CWRIS | CERTIFICATE | IR·HE·DS· | | 50 | 3 | | | | USDI BPA |
| T21N/R07E-05 | G1-*08743CWRIS | CERTIFICATE | IR·HE·DS· | | 50 | 3 | | | | USDI BPA |
| T21N/R07E-05 | G1-*08743CWRIS | CERTIFICATE | IR·HE·DS· | | 50 | 3 | | | | USDI BPA |
| T21N/R07E-07 | S1-22631CWRIS | CERTIFICATE | DS· | 0.02 | | 2 | | | | LARSON LARRY A |
| T21N/R07E-07 | S1-23029AWRIS | APPLICATION | DS· | 0.02 | | | | | | KELLY PATRIC BLAIR |
| T21N/R07E-08 | S1-*21611CWRIS | CERTIFICATE | DS· | 0.01 | | 1 | | | | KOTILA W |
| T21N/R07E-08 | S1-00024CWRIS | CERTIFICATE | DS· | 0.01 | | 1 | | | | MAIERS MAYNARD M |
| T21N/R07E-08 | S1-00496CWRIS | CERTIFICATE | DS· | 0.027 | | 1 | | | | THIEL SHELDON EGERT |
| T21N/R07E-08 | S1-069625CL | CLAIM/L | DG | | | | | JOHNSON | NEIL T. | |
| T21N/R07E-08 | S1-069626CL | CLAIM/L | DG | | | | | JOHNSON | NEIL T. | |
| T21N/R07E-08 | S1-069627CL | CLAIM/L | DG | | | | | JOHNSON | NEIL T. | |
| T21N/R07E-08 | S1-152053CL | CLAIM/L | DG | | | | | LOCKWOOD | SHIRLEY M | |
| T21N/R07E-08 | S1-20844CWRIS | CERTIFICATE | DS· | 0.01 | | 1 | | | | WILSON G F & M E |
| T21N/R07E-08 | S1-20926CWRIS | CERTIFICATE | DS· | 0.01 | | 2 | | | | CURTIS DALE ET UX |
| T21N/R07E-08 | S1-21282CWRIS | CERTIFICATE | DS· | 0.02 | | 1 | | | | FINGER ROBERT W |
| T21N/R07E-08 | S1-22474CWRIS | CERTIFICATE | DS· | 0.02 | | 1 | | | | MCLEAN SUTHERLAND |
| T21N/R07E-08 | S1-22632PWRIS | PERMIT | DM· | 0.02 | | 4 | | | | GRIMES ROBERT P. |
| T21N/R07E-08 | S1-23255CWRIS | CERTIFICATE | DS· | 0.01 | | 1 | | | | GUMSER NORMAN |
| T21N/R07E-08 | S1-23671CWRIS | CERTIFICATE | DM· | 0.01 | | 1 | | | | HILL STEVEN |
| T21N/R07E-08 | S1-23965CWRIS | CERTIFICATE | DM· | 0.02 | | 2 | | | | MARCHIONE DAVID M |
| T21N/R07E-08 | S1-23975CWRIS | CERTIFICATE | DS· | 0.01 | | 1 | | | | HUGGINS SHAWN L |
| T21N/R07E-08 | S1-24513CWRIS | CERTIFICATE | DM· | 0.02 | | 0.67 | | | | CALLIGAN WILLIAM A |
| T21N/R07E-08 | S1-24517CWRIS | CERTIFICATE | DS· | 0.02 | | 0.67 | | | | OSTROWSKI RICHARD |
| T21N/R07E-08 | S1-24570CWRIS | CERTIFICATE | DS· | 0.02 | | 0.75 | | | | HUGGINS SHAWN |

Table 3 - Water Rights in Rock Creek Basin



| Township/ Range - Section | ID Number | Type of Right | Purpose | Amount of Flow cfs | gpm | ac-ft | Units Served | Last Name | First Name | Business Name |
|---|---|---|---|---|---|---|---|---|---|---|
| T22N/R06E-22 | G1-053540CL | CLAIM/S | DG | | | | | WALSH | W. J. | |
| T22N/R06E-22 | G1-060639CL | CLAIM/S | DG ST | | | | | OLSON | GARY L. | |
| T22N/R06E-22 | G1-060639CL | CLAIM/S | DG ST | | | | | OLSON | GARY L. | |
| T22N/R06E-22 | G1-102904CL | CLAIM/S | DG ST IR | | | | | MILLER | VIOLA M | |
| T22N/R06E-22 | G1-102904CL | CLAIM/S | DG ST IR | | | | | MILLER | VIOLA M | |
| T22N/R06E-22 | G1-102904CL | CLAIM/S | DG ST IR | | | | | MILLER | VIOLA M | |
| T22N/R06E-22 | G1-123304CL | CLAIM/S | DG | | | | | COLE | SALLY | |
| T22N/R06E-22 | G1-125418CL | CLAIM/S | DG IR | | | | | PHILLIPS | CHESTER H | |
| T22N/R06E-22 | G1-125418CL | CLAIM/S | DG IR | | | | | PHILLIPS | CHESTER H | |
| T22N/R06E-22 | G1-141832CL | CLAIM/S | DG | | | | | BECKT | ROGER E | |
| T22N/R06E-23 | G1-007630CL | CLAIM/L | DG | | | | | HABENICHT | FRED V. | |
| T22N/R06E-23 | G1-012512CL | CLAIM/L | DG ST | | | | | LANE | PHILLIP A. | |
| T22N/R06E-23 | G1-012512CL | CLAIM/L | DG ST | | | | | LANE | PHILLIP A. | |
| T22N/R06E-25 | G1-008872CL | CLAIM/L | DG | | | | | SMITH | ALBERT I. | |
| T22N/R06E-25 | G1-008873CL | CLAIM/L | DG | | | | | SMITH | ALBERT I. | |
| T22N/R06E-25 | G1-025805CL | CLAIM/L | DG | | | | | JOHNSON | WENDELL C. | |
| T22N/R06E-25 | G1-028701CL | CLAIM/L | DG | | | | | COLLECCHI | SERAFINO | |
| T22N/R06E-25 | G1-081896CL | CLAIM/S | DG | | | | | COLLECCHI | ALEXANDER | |
| T22N/R06E-25 | G1-085363CL | CLAIM/S | DG | | | | | SHIMMEL | JOSEPH | |
| T22N/R06E-25 | G1-087454CL | CLAIM/S | DG ST IR | | | | | MUCHOW | JOE E. JR. | |
| T22N/R06E-25 | G1-087454CL | CLAIM/S | DG ST IR | | | | | MUCHOW | JOE E. JR. | |
| T22N/R06E-25 | G1-087454CL | CLAIM/S | DG ST IR | | | | | MUCHOW | JOE E. JR. | |
| T22N/R06E-25 | G1-149509CL | CLAIM/S | DG IR | | | | | GARRETT | VERNON L | |
| T22N/R06E-25 | G1-149509CL | CLAIM/S | DG IR | | | | | GARRETT | VERNON L | |
| T22N/R06E-25 | G1-161729CL | CLAIM/L | DG | | | | | SMITH | ALBERT I | |
| T22N/R06E-25 | G1-161730CL | CLAIM/L | DG IR | | | | | SMITH | ALBERT I | |
| T22N/R06E-25 | G1-161730CL | CLAIM/L | DG IR | | | | | SMITH | ALBERT I | |
| T22N/R06E-25 | G1-20735AWRIS | APPLICATION | DM· | | 75 | | | | | CHAMBERS WALTER A |
| T22N/R06E-25 | G1-23566CWRIS | CERTIFICATE | DM· | | 40 | 7.5 | | | | KIELLAND A R |
| T22N/R06E-25 | S1-123815CL | CLAIM/S | IR | | | | | PARADIS | REUEL L | |
| T22N/R06E-26 | G1-003944CL | CLAIM/L | DG | | | | | BUTCHER | KARL M. | |
| T22N/R06E-26 | G1-083904CL | CLAIM/S | DG IR | | | | | BARTH | HAROLD A | |
| T22N/R06E-26 | G1-083904CL | CLAIM/S | DG IR | | | | | BARTH | HAROLD A | |
| T22N/R06E-26 | G1-141975CL | CLAIM/L | DG ST IR | | | | 2 | BELLEMAN | GUY W | |
| T22N/R06E-26 | G1-141975CL | CLAIM/L | DG ST IR | | | | 2 | BELLEMAN | GUY W | |
| T22N/R06E-26 | G1-141975CL | CLAIM/L | DG ST IR | | | | 2 | BELLEMAN | GUY W | |
| T22N/R06E-27 | G1-000891CL | CLAIM/L | DG | | | | | SILVESTRI | THOMAS MARTIN | |
| T22N/R06E-27 | G1-001320CL | CLAIM/L | DG ST | | | | | NIX | MARK C. | |
| T22N/R06E-27 | G1-001320CL | CLAIM/L | DG ST | | | | | NIX | MARK C. | |
| T22N/R06E-27 | G1-001949CL | CLAIM/L | DG | | | | | BARBER | DAVID M. | |
| T22N/R06E-27 | G1-014097CL | CLAIM/L | DG IR | | | | 1 | MOSSANO | NIBBS | |
| T22N/R06E-27 | G1-014097CL | CLAIM/L | DG IR | | | | 1 | MOSSANO | NIBBS | |
| T22N/R06E-27 | G1-015416CL | CLAIM/L | DG | | | | | HURLEY | WARREN S. | |

Table 3 - Water Rights in Rock Creek Basin



| Township/ Range - Section | ID Number | Type of Right | Purpose | Amount of Flow cfs | gpm | ac-ft | Units Served | Last Name | First Name | Business Name |
|---|---|---|---|---|---|---|---|---|---|---|
| T22N/R06E-27 | G1-018702CL | CLAIM/L | DG IR | | | | 1 | DAVENPORT | ARTHUR L. | |
| T22N/R06E-27 | G1-018702CL | CLAIM/L | DG IR | | | | 1 | DAVENPORT | ARTHUR L. | |
| T22N/R06E-27 | G1-029736CL | CLAIM/L | DG | | | | | SONTAG | ARTHUR J. | |
| T22N/R06E-27 | G1-038575CL | CLAIM/L | DG | | | | | ROSS | DAVID J. | |
| T22N/R06E-27 | G1-050206CL | CLAIM/L | DG | | | | | PALMER | CHARLES E. | |
| T22N/R06E-27 | G1-051927CL | CLAIM/S | DG | | | | | LINDELL | HARRY W. | |
| T22N/R06E-27 | G1-062905CL | CLAIM/S | DG | | | | | GJEMSE | JOSEPH A. | |
| T22N/R06E-27 | G1-066368CL | CLAIM/S | DG | | | | | ASHER | WILLIAM R. | |
| T22N/R06E-27 | G1-070941CL | CLAIM/S | DG | | | | | LEEK | HAZEL M. | |
| T22N/R06E-27 | G1-076457CL | CLAIM/L | DG | | | | | RAUB | GERALD F. | |
| T22N/R06E-27 | G1-081100CL | CLAIM/S | DG | | | | | BUTLER | GLENN L. | |
| T22N/R06E-27 | G1-088892CL | CLAIM/L | DG | | | | | CHAMBERS | JUNE M. | |
| T22N/R06E-27 | G1-106079CL | CLAIM/S | DG IR | | | | | GILMORE | DANIEL H | |
| T22N/R06E-27 | G1-106079CL | CLAIM/S | DG IR | | | | | GILMORE | DANIEL H | |
| T22N/R06E-27 | G1-111497CL | CLAIM/L | DG | | | | | ANDERSON | PATRICK W | |
| T22N/R06E-27 | G1-121852CL | CLAIM/S | DG IR | | | | | BENEDICT | ELMER B | |
| T22N/R06E-27 | G1-121852CL | CLAIM/S | DG IR | | | | | BENEDICT | ELMER B | |
| T22N/R06E-27 | G1-131391CL | CLAIM/L | DG | | | | | SOUSHEK | BEN R | |
| T22N/R06E-27 | G1-131392CL | CLAIM/L | DG | | | | | SOUSHEK | BEN R | |
| T22N/R06E-27 | G1-131974CL | CLAIM/S | DG | | | | | DZIEDZIC | ALFRED S | |
| T22N/R06E-27 | G1-131975CL | CLAIM/S | DG | | | | | DZIEDZIC | ALFRED S | |
| T22N/R06E-27 | G1-131976CL | CLAIM/S | DG | | | | | DZIEDZIC | ALFRED S | |
| T22N/R06E-27 | G1-131977CL | CLAIM/S | DG | | | | | DZIEDZIC | ALFRED S | |
| T22N/R06E-27 | G1-139096CL | CLAIM/L | DG | | | | | SOUSHEK | EARL A | |
| T22N/R06E-27 | G1-143622CL | CLAIM/S | DG | | | | | MORRIS | EVAN | |
| T22N/R06E-27 | G1-150018CL | CLAIM/L | DG IR | | | | | OLSEN | JULIAN C | |
| T22N/R06E-27 | G1-150018CL | CLAIM/L | DG IR | | | | | OLSEN | JULIAN C | |
| T22N/R06E-27 | G1-23568CWRIS | CERTIFICATE | DM | | 20 | 8.6 | | | | BURKE GERALD E |
| T22N/R06E-27 | G1-25642 | APPLICATION | MU | | 1000 | | | NELSON | JUDY | COVINGTON WATER DISTRICT |
| T22N/R06E-27 | S1-032438CL | CLAIM/S | DG | | | | | HURLEY | WARREN | |
| T22N/R06E-27 | S1-070940CL | CLAIM/S | DG | | | | | LEEK | HAZEL M. | |
| T22N/R06E-27 | S1-094137CL | CLAIM/L | DG | | | | | MURPHY | RAY D | |
| T22N/R06E-27 | S1-112550CL | CLAIM/S | DG | | | | | ZEPERNICK | GARY F | |
| T22N/R06E-27 | S1-123056CL | CLAIM/S | DG IR | | | | | GOLDMANN | GEORGE S | |
| T22N/R06E-27 | S1-123056CL | CLAIM/S | DG IR | | | | | GOLDMANN | GEORGE S | |
| T22N/R06E-27 | S1-140226CL | CLAIM/S | DG | | | | | MONEY | JAMES C | |
| T22N/R06E-27 | S1-140954CL | CLAIM/S | DG IR | | | | | MONEY | JAMES L | |
| T22N/R06E-27 | S1-140954CL | CLAIM/S | DG IR | | | | | MONEY | JAMES L | |
| T22N/R06E-27 | S1-145947CL | CLAIM/S | DG IR | | | | | LANGHURST | ROBERT R | |
| T22N/R06E-27 | S1-145947CL | CLAIM/S | DG IR | | | | | LANGHURST | ROBERT R | |
| T22N/R06E-27 | S1-147624CL | CLAIM/L | DG IR | | | | | TATE | JOHN A | |
| T22N/R06E-27 | S1-147624CL | CLAIM/L | DG IR | | | | | TATE | JOHN A | |
| T22N/R06E-27 | S1-150017CL | CLAIM/L | DG IR | | | | 1 | SHINN | BARBARA L | |

Table 3 - Water Rights in Rock Creek Basin

| Township/ Range - Section | ID Number | Type of Right | Purpose | Amount of Flow cfs | gpm | ac-ft | Units Served | Last Name | First Name | Business Name |
|---|---|---|---|---|---|---|---|---|---|---|
| T22N/R06E-27 | S1-150017CL | CLAIM/L | DG IR | | | | 1 | SHINN | BARBARA L | |
| T22N/R06E-27 | S1-150019CL | CLAIM/L | DG IR | | | | 1 | OLSEN | JULIAN C | |
| T22N/R06E-27 | S1-150019CL | CLAIM/L | DG IR | | | | 1 | OLSEN | JULIAN C | |
| T22N/R06E-27 | S1-161831CL | CLAIM/S | DG IR | | | | | SCHAEFFER | DWIGHT R | |
| T22N/R06E-27 | S1-161831CL | CLAIM/S | DG IR | | | | | SCHAEFFER | DWIGHT R | |
| T22N/R06E-27 | S1-20894CWRIS | CERTIFICATE | DS· | 0.02 | | 1 | | | | ROSS DAVID J |
| T22N/R06E-27 | S1-21789PWRIS | PERMIT | DS· | 0.02 | | 1 | | | | STEELE FLOYD M |
| T22N/R06E-36 | G1-034964CL | CLAIM/S | DG | | | | | VISCONIC | FRANK E. | |
| T22N/R06E-36 | G1-105440CL | CLAIM/S | DG IR | | | | | CLOUGH | CALEB N JR | |
| T22N/R06E-36 | G1-105440CL | CLAIM/S | DG IR | | | | | CLOUGH | CALEB N JR | |
| T22N/R06E-36 | G1-24502 | CERTIFICATE | MU· | | 100 | 45 | | | | KCWD #105 |
| T22N/R06E-36 | G1-24503AWRIS | APPLICATION | DM· | | 200 | | | | | KCWD #43 |
| T22N/R06E-36 | G1-26929 | APPLICATION | IR· | | 100 | | | | | King County Parks Division |
| T22N/R06E-36 | S1-*03700AWRIS | APPLICATION | DS· | 10 | | | | | | CLARK I C |
| T22N/R06E-36 | S1-*20279CWRIS | CERTIFICATE | MI· | 2.7 | | 744 | | | | BURLINGTON NORTHERN |
| T22N/R07E-27 | G1-25348CWRIS | CERTIFICATE | DS· | | 20 | 0.5 | | | | STOLSIG SR R & P |
| T22N/R07E-28 | G1-103045CL | CLAIM/L | DG | | | | | ALBRECHT | ARLINE | |
| T22N/R07E-28 | G1-113365CL | CLAIM/L | DG | | | | | | | EVERGREEN WATER / |
| T22N/R07E-28 | G1-124715CL | CLAIM/S | DG | | | | | OLSON | BENNIE T | |
| T22N/R07E-28 | G1-22626CWRIS | CERTIFICATE | DM· | | 75 | 50 | | | | EVERGREEN WTE IMP AN |
| T22N/R07E-28 | G1-22717AWRIS | APPLICATION | DM· | | 25 | | | | | CHAVES HERNANDO |
| T22N/R07E-28 | G1-22718CWRIS | CERTIFICATE | DM· | | 115 | 90 | | | | CHAVES HERNANDO |
| T22N/R07E-28 | G1-24116CWRIS | CERTIFICATE | DM· | | 60 | 50 | | | | EVERGREEN WATER ASSOC |
| T22N/R07E-28 | G1-24305AWRIS | APPLICATION | DM· | | 3 | | | | | SMITH JAMES JR |
| T22N/R07E-30 | G1-145341CL | CLAIM/S | DG ST IR | | | | | TRUEBLOOD | LESLIE L | |
| T22N/R07E-30 | G1-145341CL | CLAIM/S | DG ST IR | | | | | TRUEBLOOD | LESLIE L | |
| T22N/R07E-30 | G1-145341CL | CLAIM/S | DG ST IR | | | | | TRUEBLOOD | LESLIE L | |
| T22N/R07E-30 | G1-153630CL | CLAIM/S | DG ST IR | | | | | HUBBELL | ORVIS E | |
| T22N/R07E-30 | G1-153630CL | CLAIM/S | DG ST IR | | | | | HUBBELL | ORVIS E | |
| T22N/R07E-30 | G1-153630CL | CLAIM/S | DG ST IR | | | | | HUBBELL | ORVIS E | |
| T22N/R07E-30 | G1-25137CWRIS | CERTIFICATE | DM· | | 13 | 4.5 | | | | ASSOC WTR SYS 11 |
| T22N/R07E-32 | B1-200266CL | CLAIM/S | DG IR | | | | 0 | KOMBOL | BERNELL | |
| T22N/R07E-32 | B1-200266CL | CLAIM/S | DG IR | | | | 0 | KOMBOL | BERNELL | |
| T22N/R07E-32 | G1-*10576CWRIS | CERTIFICATE | DS· | | 15 | 1 | | | | COLLECCHI A D |
| T22N/R07E-32 | G1-001073CL | CLAIM/L | DG | | | | | VERSOI | CLIFFORD A. | |
| T22N/R07E-32 | G1-001229CL | CLAIM/L | DG | | | | | FINNEGAN | CLAYTON B. | |
| T22N/R07E-32 | G1-003321CL | CLAIM/L | DG | | | | | STREAM | ALBERT J. | |
| T22N/R07E-32 | G1-004398CL | CLAIM/L | DG | | | | | ANDERSON | THEODORE B. | |
| T22N/R07E-32 | G1-010180CL | CLAIM/L | DG | | | | | JOHNSON | WALTER | |
| T22N/R07E-32 | G1-020190CL | CLAIM/L | DG | | | | | COCKERILL | WALTER C. | |
| T22N/R07E-32 | G1-022298CL | CLAIM/L | DG | | | | | HAMMOND | HERBERT E. | |
| T22N/R07E-32 | G1-027176CL | CLAIM/L | DG | | | | | LAIRD | THOMAS J. | |
| T22N/R07E-32 | G1-028165CL | CLAIM/L | DG | | | | | KNOWLES | LEORA B. | |

Table 3 - Water Rights in Rock Creek Basin

| Township/ Range - Section | ID Number | Type of Right | Purpose | Amount of Flow cfs | gpm | ac-ft | Units Served | Last Name | First Name | Business Name |
|---|---|---|---|---|---|---|---|---|---|---|
| T22N/R07E-32 | G1-036968CL | CLAIM/L | DG | | | | | BEGHTEL | DEWEY | |
| T22N/R07E-32 | G1-043811CL | CLAIM/S | DG | | | | | HELLAND | MILTON A. | |
| T22N/R07E-32 | G1-047960CL | CLAIM/S | DG | | | | | MYLNAR | ADA | |
| T22N/R07E-32 | G1-060810CL | CLAIM/S | DG | | | | | ATWOOD | HOWARD C. | |
| T22N/R07E-32 | G1-071419CL | CLAIM/L | DG | | | | | ALMQUIST | HOWARD | |
| T22N/R07E-32 | G1-072557CL | CLAIM/S | DG | | | | | HAMILTON | JUDITH H. | |
| T22N/R07E-32 | G1-079381CL | CLAIM/L | DG | | | | | HARLIN | ALLAN J. | |
| T22N/R07E-32 | G1-081895CL | CLAIM/S | DG | | | | | COLLECCHI | ALEXANDER | |
| T22N/R07E-32 | G1-087293CL | CLAIM/S | DG IR | | | | | HALL | VIVIAN M. | |
| T22N/R07E-32 | G1-087293CL | CLAIM/S | DG IR | | | | | HALL | VIVIAN M. | |
| T22N/R07E-32 | G1-100721CL | CLAIM/S | DG | | | | | SUTTON | FRANK E | |
| T22N/R07E-32 | G1-101071CL | CLAIM/S | DG IR | | | | | MITTENDORF | JACK A | |
| T22N/R07E-32 | G1-101071CL | CLAIM/S | DG IR | | | | | MITTENDORF | JACK A | |
| T22N/R07E-32 | G1-102201CL | CLAIM/L | DG | | | | | KREMER | MATT N | |
| T22N/R07E-32 | G1-103605CL | CLAIM/S | DG | | | | | HAMMERSTROM | ETHEL P | |
| T22N/R07E-32 | G1-103622CL | CLAIM/L | DG ST IR | | | | 1 | LUCAS | GARY D | |
| T22N/R07E-32 | G1-103622CL | CLAIM/L | DG ST IR | | | | 1 | LUCAS | GARY D | |
| T22N/R07E-32 | G1-103622CL | CLAIM/L | DG ST IR | | | | 1 | LUCAS | GARY D | |
| T22N/R07E-32 | G1-114173CL | CLAIM/L | DG | | | | | FORRY | HAROLD M | |
| T22N/R07E-32 | G1-121414CL | CLAIM/S | DG | | | | | BREMMEYER | BILL | |
| T22N/R07E-32 | G1-123433CL | CLAIM/L | DG | | | | | ANDERSON | RONALD D | |
| T22N/R07E-32 | G1-123434CL | CLAIM/L | DG | | | | | ANDERSON | RONALD D | |
| T22N/R07E-32 | G1-124626CL | CLAIM/S | DG | | | | | SOGURA | MICHAEL A | |
| T22N/R07E-32 | G1-125595CL | CLAIM/L | DG | | | | | JOSWICK | JAMES G | |
| T22N/R07E-32 | G1-141842CL | CLAIM/L | DG ST | | | | | DOLL | HARLAN L | |
| T22N/R07E-32 | G1-141842CL | CLAIM/L | DG ST | | | | | DOLL | HARLAN L | |
| T22N/R07E-32 | G1-146883CL | CLAIM/L | DG | | | | | PALMER | SUSAN | |
| T22N/R07E-32 | G1-149868CL | CLAIM/S | DG | | | | | COULON | GENE L | |
| T22N/R07E-32 | G1-158777CL | CLAIM/L | DG | | | | | HUNT | HUGH H | |
| T22N/R07E-32 | G1-160525CL | CLAIM/S | DG | | | | | LUNDER | CLARENCE A | |
| T22N/R07E-32 | G1-161505CL | CLAIM/S | DG IR | | | | | SAFTICH | JOE S | |
| T22N/R07E-32 | G1-161505CL | CLAIM/S | DG IR | | | | | SAFTICH | JOE S | |
| T22N/R07E-32 | G1-163360CL | CLAIM/L | DG | | | | | TRICK | STUART E | |
| T22N/R07E-32 | G1-22668PWRIS | PERMIT | DM· | | 6 | 7.2 | | | | SCHMIDT C E & V P |
| T22N/R07E-32 | G1-22815AWRIS | APPLICATION | DM· | | 4 | | | | | ANDERSON RONALD D |
| T22N/R07E-32 | G1-23295PWRIS | PERMIT | DM· | | 14 | 10 | | | | TOTAL CONSTRUCTION |
| T22N/R07E-32 | G1-23393CWRIS | CERTIFICATE | DM· | | 10 | 8 | | | | DRLLEVICH CONST INC |
| T22N/R07E-32 | G1-24632CWRIS | CERTIFICATE | DM· | | 24 | 5 | | | | BLACKWATER CO-OP |
| T22N/R07E-32 | G1-27810 | APPLICATION | IR·DM· | | 10 | | 9 | | | Lake Retreat Firs #1 |
| T22N/R07E-32 | G1-27810 | APPLICATION | IR·DM· | | 10 | | 9 | | | Lake Retreat Firs #1 |
| T22N/R07E-32 | G1-28063 | APPLICATION | DM· | | 20 | | | ZIESING | RON | LAKE RETREAT CAMP & CONFERENCE |
| T22N/R07E-32 | S1-*13661PWRIS | PERMIT | IR·DS· | 0.08 | | | | | | DRAGER O |
| T22N/R07E-32 | S1-*13661PWRIS | PERMIT | IR·DS· | 0.08 | | | | | | DRAGER O |

Table 3 - Water Rights in Rock Creek Basin



| Township/ Range - Section | ID Number | Type of Right | Purpose | Amount of Flow cfs | gpm | ac-ft | Units Served | Last Name | First Name | Business Name |
|---|---|---|---|---|---|---|---|---|---|---|
| T22N/R07E-32 | S1-*17772CWRIS | CERTIFICATE | ST·DM· | 0.06 | | | | | | LITRAS G ET AL |
| T22N/R07E-32 | S1-*17772CWRIS | CERTIFICATE | ST·DM· | 0.06 | | | | | | LITRAS G ET AL |
| T22N/R07E-32 | S1-016702CL | CLAIM/L | DG | | | | | DEROUIN | WALTER | |
| T22N/R07E-32 | S1-021596CL | CLAIM/L | DG | | | | | BEARD | MARTIN | |
| T22N/R07E-32 | S1-022299CL | CLAIM/L | DG | | | | | HAMMOND | HERBERT E. | |
| T22N/R07E-32 | S1-060578CL | CLAIM/L | DG | | | | | STARR | SIDNEY R. | |
| T22N/R07E-32 | S1-071899CL | CLAIM/S | DG | | | | | HEALY | FRANK J. | |
| T22N/R07E-32 | S1-080356CL | CLAIM/S | DG | | | | | BELTRAMO | JOSEPH G. | |
| T22N/R07E-32 | S1-082719CL | CLAIM/S | DG | | | | | ARENS | HEINZ L. | |
| T22N/R07E-32 | S1-095825CL | CLAIM/S | DG | | | | | LANGLAND | OLAF | |
| T22N/R07E-32 | S1-115228CL | CLAIM/S | DG IR | | | | | HEASLIP | W J | |
| T22N/R07E-32 | S1-115228CL | CLAIM/S | DG IR | | | | | HEASLIP | W J | |
| T22N/R07E-32 | S1-118376CL | CLAIM/S | DG IR | | | | | ENGESET | SYDNEY | |
| T22N/R07E-32 | S1-118376CL | CLAIM/S | DG IR | | | | | ENGESET | SYDNEY | |
| T22N/R07E-32 | S1-119672CL | CLAIM/L | DG | | | | | HARLIN | ALLAN J | |
| T22N/R07E-32 | S1-125580CL | CLAIM/S | DG IR | | | | | FARDIG | DELANO | |
| T22N/R07E-32 | S1-125580CL | CLAIM/S | DG IR | | | | | FARDIG | DELANO | |
| T22N/R07E-32 | S1-132571CL | CLAIM/L | IR | | | | | GILBERTSON | GORDON C | |
| T22N/R07E-32 | S1-149455CL | CLAIM/S | DG IR | | | | | MEREDITH | WM G | |
| T22N/R07E-32 | S1-149455CL | CLAIM/S | DG IR | | | | | MEREDITH | WM G | |
| T22N/R07E-32 | S1-149869CL | CLAIM/S | IR | | | | | COULON | GENE L | |
| T22N/R07E-32 | S1-155574CL | CLAIM/L | DG | | | | | | | RAVENSDALE WATER SUP CO |
| T22N/R07E-32 | S1-160835CL | CLAIM/S | DG | | | | | RAUMA | MARTIN J | |
| T22N/R07E-32 | S1-20757CWRIS | CERTIFICATE | DS· | 0.01 | | 1 | | | | GALVIN EDGAR J |
| T22N/R07E-34 | G1-119254CL | CLAIM/S | DG ST IR | | | | | SPRAU | DURAND T | |
| T22N/R07E-34 | G1-119254CL | CLAIM/S | DG ST IR | | | | | SPRAU | DURAND T | |
| T22N/R07E-34 | G1-119254CL | CLAIM/S | DG ST IR | | | | | SPRAU | DURAND T | |
| T22N/R07E-34 | G1-25557CWRIS | CERTIFICATE | DM· | | 13 | 4.5 | | | | ALMONT KIRBY L |
| T22N/R07E-34 | S1-095029CL | CLAIM/L | ST IR | | | | 20 | LOUPE | GERARD | |
| T22N/R07E-34 | S1-095029CL | CLAIM/L | ST IR | | | | 20 | LOUPE | GERARD | |
| T22N/R07E-34 | S1-095030CL | CLAIM/L | ST IR | | | | 20 | FANCHER | HUGH L | |
| T22N/R07E-34 | S1-095030CL | CLAIM/L | ST IR | | | | 20 | FANCHER | HUGH L | |
| T22N/R07E-34 | S1-141934CL | CLAIM/S | IR | | | | | ANDERSON | LEIGHTON R | |
| T22N/R07E-34 | S1-20221CWRIS | CERTIFICATE | /VL·ST·IR·FS | 0.03 | | 11 | | | | TRICOLI BART |
| T22N/R07E-34 | S1-20221CWRIS | CERTIFICATE | /VL·ST·IR·FS | 0.03 | | 11 | | | | TRICOLI BART |
| T22N/R07E-34 | S1-20221CWRIS | CERTIFICATE | /VL·ST·IR·FS | 0.03 | | 11 | | | | TRICOLI BART |
| T22N/R07E-34 | S1-20221CWRIS | CERTIFICATE | /VL ST·IR·FS | 0.03 | | 11 | | | | TRICOLI BART |

Table 3 - Water Rights in Rock Creek Basin



| Township/ Range - Section | ID Number | Type of Right | Purpose | Amount of Flow cfs | gpm | ac-ft | Units Served | Last Name | First Name | Business Name |
|---|---|---|---|---|---|---|---|---|---|---|
| T22N/R07E-34 | S1-20222CWRIS | CERTIFICATE | ST·DS·DG· | 0.01 | | 4 | | | | TRICOLI BART |
| T22N/R07E-34 | S1-20222CWRIS | CERTIFICATE | ST·DS·DG· | 0.01 | | 4 | | | | TRICOLI BART |
| T22N/R07E-34 | S1-20222CWRIS | CERTIFICATE | ST·DS·DG· | 0.01 | | 4 | | | | TRICOLI BART |
| | | | Totals | 13.437 | 2372 | 1233.51 | | | | |

Extracted from the Washington State Department of Ecology Water Right Application Tracking System (WRATS) Database

**Notes:** 1) WRATS database queried by whole Township, Range, and Section. Some entries may be outside of the Rock Creek boundary.

2) Use Codes: ST - Stock Watering; DG - Domestic; IR - Irrigation; DG - ; MU - Municipal; DM - ; MI - Industrial

2) Excludes Water Rights for the City of Kent (see text)

# Table 4 - Water Production History at Clark Springs

| | Monthly Water Production from Clark Springs in cfs | | | | | | |
|---|---|---|---|---|---|---|---|
| | Total and Average | | Production from each Facility | | | | |
| Month and Year | Combined Total | 1-Year Running Average | Gallery | Well 1 | Well 2 | Well 3 | Total Wells |
| Jan-86 | 4.48 | | 4.48 | 0.00 | 0.00 | 0.00 | 0.00 |
| Feb-86 | 7.69 | | 7.69 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mar-86 | 6.20 | | 6.17 | 0.00 | 0.00 | 0.03 | 0.03 |
| Apr-86 | 6.80 | | 6.79 | 0.00 | 0.00 | 0.00 | 0.01 |
| May-86 | 7.31 | | 6.74 | 0.56 | 0.00 | 0.01 | 0.56 |
| Jun-86 | 7.88 | | *0.14* | *2.06* | *1.55* | *4.13* | *7.74* |
| Jul-86 | 7.03 | | *0.29* | *2.00* | *1.50* | *3.24* | *6.74* |
| Aug-86 | 6.11 | | *0.47* | *0.90* | *1.75* | *2.99* | *5.64* |
| Sep-86 | 6.77 | | *3.33* | *0.57* | *0.67* | *2.20* | *3.44* |
| Oct-86 | 6.02 | | *4.76* | *0.05* | *0.60* | *0.62* | *1.27* |
| Nov-86 | 5.54 | | *4.40* | *0.77* | *0.21* | *0.15* | *1.13* |
| Dec-86 | 8.86 | 6.72 | *7.94* | *0.88* | *0.03* | *0.00* | *0.92* |
| Jan-87 | 7.61 | 6.99 | 7.61 | 0.00 | 0.00 | 0.00 | 0.00 |
| Feb-87 | 7.45 | 6.97 | 7.45 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mar-87 | 8.20 | 7.13 | 8.20 | 0.00 | 0.00 | 0.00 | 0.00 |
| Apr-87 | 6.80 | 7.13 | 6.80 | 0.00 | 0.00 | 0.00 | 0.00 |
| May-87 | 6.20 | 7.04 | 6.19 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jun-87 | 7.50 | 7.01 | 7.45 | 0.04 | 0.01 | 0.00 | 0.05 |
| Jul-87 | 6.55 | 6.97 | 5.11 | 1.14 | 0.27 | 0.03 | 1.44 |
| Aug-87 | 6.44 | 7.00 | 1.90 | 2.81 | 1.59 | 0.14 | 4.54 |
| Sep-87 | 6.23 | 6.95 | 1.15 | 1.66 | 3.41 | 0.00 | 5.07 |
| Oct-87 | 6.14 | 6.96 | 0.65 | 1.78 | 3.71 | 0.00 | 5.49 |
| Nov-87 | 4.92 | 6.91 | 3.24 | 0.60 | 1.08 | 0.00 | 1.68 |
| Dec-87 | 4.07 | 6.51 | 4.07 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jan-88 | 4.74 | 6.27 | 4.74 | 0.00 | 0.00 | 0.00 | 0.00 |
| Feb-88 | 5.12 | 6.08 | 5.12 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mar-88 | 5.45 | 5.85 | 5.44 | 0.01 | 0.00 | 0.00 | 0.01 |
| Apr-88 | 6.56 | 5.83 | 6.56 | 0.00 | 0.00 | 0.00 | 0.00 |
| May-88 | 7.07 | 5.90 | 7.07 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jun-88 | 6.83 | 5.84 | 6.83 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jul-88 | 6.15 | 5.81 | 6.15 | 0.00 | 0.00 | 0.00 | 0.00 |
| Aug-88 | 6.53 | 5.82 | 6.53 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sep-88 | 5.93 | 5.79 | 5.93 | 0.00 | 0.00 | 0.00 | 0.00 |
| Oct-88 | 6.03 | 5.78 | 6.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| Nov-88 | 6.56 | 5.92 | 6.56 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dec-88 | 6.10 | 6.09 | 6.10 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jan-89 | 7.21 | 6.29 | 7.21 | 0.00 | 0.00 | 0.00 | 0.00 |
| Feb-89 | 7.42 | 6.49 | 7.42 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mar-89 | 5.90 | 6.52 | 5.90 | 0.00 | 0.00 | 0.00 | 0.00 |
| Apr-89 | 6.97 | 6.56 | 6.12 | 0.00 | 0.00 | 0.86 | 0.86 |
| May-89 | 7.80 | 6.62 | 7.65 | 0.00 | 0.00 | 0.15 | 0.15 |
| Jun-89 | 6.64 | 6.60 | 6.64 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jul-89 | 5.78 | 6.57 | 5.78 | 0.00 | 0.00 | 0.00 | 0.00 |
| Aug-89 | 5.84 | 6.52 | 5.84 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sep-89 | 5.51 | 6.48 | 5.51 | 0.00 | 0.00 | 0.00 | 0.00 |
| Oct-89 | 5.83 | 6.46 | 5.83 | 0.00 | 0.00 | 0.00 | 0.00 |
| Nov-89 | 5.56 | 6.38 | 5.56 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dec-89 | 5.11 | 6.30 | 5.11 | 0.00 | 0.00 | 0.00 | 0.00 |

## Table 4 - Water Production History at Clark Springs



| | Monthly Water Production from Clark Springs in cfs | | | | | | |
|---|---|---|---|---|---|---|---|
| | Total and Average | | Production from each Facility | | | | |
| Month and Year | Combined Total | 1-Year Running Average | Gallery | Well 1 | Well 2 | Well 3 | Total Wells |
| Jan-90 | 6.91 | 6.27 | 6.91 | 0.00 | 0.00 | 0.00 | 0.00 |
| Feb-90 | 6.83 | 6.22 | 6.83 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mar-90 | 6.49 | 6.27 | 6.48 | 0.00 | 0.00 | 0.00 | 0.00 |
| Apr-90 | 7.49 | 6.32 | 7.49 | 0.00 | 0.00 | 0.00 | 0.00 |
| May-90 | 6.81 | 6.23 | 6.81 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jun-90 | 6.91 | 6.26 | 6.91 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jul-90 | 7.00 | 6.36 | 7.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Aug-90 | 6.20 | 6.39 | 6.14 | 0.06 | 0.00 | 0.00 | 0.06 |
| Sep-90 | 5.48 | 6.38 | 5.48 | 0.00 | 0.00 | 0.00 | 0.00 |
| Oct-90 | 6.33 | 6.43 | 6.33 | 0.00 | 0.00 | 0.00 | 0.00 |
| Nov-90 | 6.48 | 6.50 | 6.45 | 0.01 | 0.01 | 0.01 | 0.03 |
| Dec-90 | 6.80 | 6.64 | 6.80 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jan-91 | 6.73 | 6.63 | 6.73 | 0.00 | 0.00 | 0.00 | 0.00 |
| Feb-91 | 6.19 | 6.58 | 6.19 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mar-91 | 5.62 | 6.50 | 5.62 | 0.00 | 0.00 | 0.00 | 0.00 |
| Apr-91 | 6.51 | 6.42 | 6.50 | 0.00 | 0.00 | 0.00 | 0.00 |
| May-91 | 6.43 | 6.39 | 6.43 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jun-91 | 5.89 | 6.30 | 5.89 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jul-91 | 6.25 | 6.24 | 6.23 | 0.00 | 0.00 | 0.01 | 0.02 |
| Aug-91 | 5.79 | 6.21 | 5.76 | 0.00 | 0.01 | 0.01 | 0.03 |
| Sep-91 | 5.92 | 6.25 | 5.92 | 0.00 | 0.00 | 0.00 | 0.00 |
| Oct-91 | 5.60 | 6.18 | 5.60 | 0.00 | 0.00 | 0.00 | 0.00 |
| Nov-91 | 5.11 | 6.07 | 5.11 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dec-91 | 6.19 | 6.02 | 6.19 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jan-92 | 6.02 | 5.96 | 6.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| Feb-92 | 6.24 | 5.96 | 6.24 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mar-92 | 6.48 | 6.04 | 6.48 | 0.00 | 0.00 | 0.00 | 0.00 |
| Apr-92 | 6.27 | 6.02 | 6.27 | 0.00 | 0.00 | 0.00 | 0.00 |
| May-92 | 5.95 | 5.98 | 5.95 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jun-92 | 6.40 | 6.02 | 6.40 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jul-92 | 5.68 | 5.97 | 5.68 | 0.00 | 0.00 | 0.00 | 0.00 |
| Aug-92 | 5.86 | 5.98 | 5.86 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sep-92 | 5.80 | 5.97 | 5.80 | 0.00 | 0.00 | 0.00 | 0.00 |
| Oct-92 | 5.35 | 5.95 | 5.34 | 0.00 | 0.00 | 0.00 | 0.00 |
| Nov-92 | 5.42 | 5.97 | 5.42 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dec-92 | 6.39 | 5.99 | 6.36 | 0.00 | 0.01 | 0.02 | 0.03 |
| Jan-93 | 6.02 | 5.99 | 6.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| Feb-93 | 5.87 | 5.96 | 5.87 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mar-93 | 6.45 | 5.96 | 6.35 | 0.00 | 0.03 | 0.06 | 0.09 |
| Apr-93 | 6.32 | 5.96 | 6.32 | 0.00 | 0.00 | 0.00 | 0.00 |
| May-93 | 4.50 | 5.84 | 4.50 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jun-93 | 6.10 | 5.81 | 6.10 | 0.00 | 0.00 | 0.00 | 0.01 |
| Jul-93 | 4.82 | 5.74 | 4.82 | 0.00 | 0.00 | 0.00 | 0.00 |
| Aug-93 | 5.92 | 5.75 | 5.91 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sep-93 | 5.62 | 5.73 | 5.62 | 0.00 | 0.00 | 0.00 | 0.00 |
| Oct-93 | 4.92 | 5.70 | 4.92 | 0.00 | 0.00 | 0.00 | 0.00 |
| Nov-93 | 5.87 | 5.73 | 5.87 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dec-93 | 4.14 | 5.55 | 4.14 | 0.00 | 0.00 | 0.00 | 0.00 |

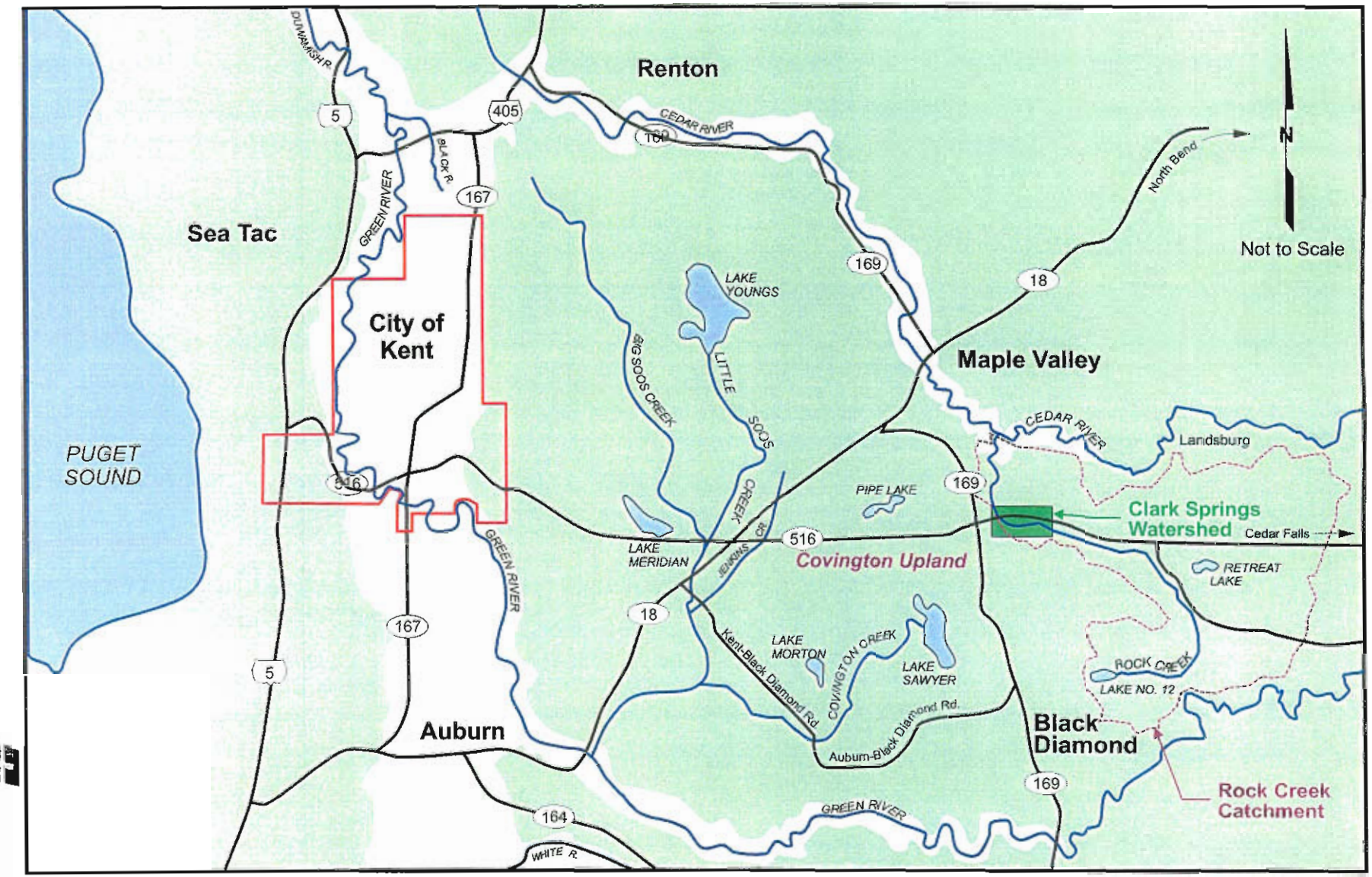
| | Monthly Water Production from Clark Springs in cfs | | | | | | |
|---|---|---|---|---|---|---|---|
| | Total and Average | | Production from each Facility | | | | |
| Month and Year | Combined Total | 1-Year Running Average | Gallery | Well 1 | Well 2 | Well 3 | Total Wells |
| Jan-94 | 5.93 | 5.54 | 5.93 | 0.00 | 0.00 | 0.00 | 0.00 |
| Feb-94 | 6.27 | 5.57 | 6.27 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mar-94 | 6.99 | 5.62 | 6.98 | 0.00 | 0.00 | 0.00 | 0.00 |
| Apr-94 | 6.61 | 5.64 | 6.61 | 0.00 | 0.00 | 0.00 | 0.00 |
| May-94 | 6.46 | 5.80 | 6.46 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jun-94 | 5.91 | 5.79 | 5.91 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jul-94 | 5.49 | 5.84 | 5.49 | 0.00 | 0.00 | 0.00 | 0.00 |
| Aug-94 | 6.17 | 5.86 | 6.17 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sep-94 | 5.74 | 5.87 | 5.74 | 0.00 | 0.00 | 0.00 | 0.00 |
| Oct-94 | 5.61 | 5.93 | 5.50 | 0.03 | 0.05 | 0.03 | 0.11 |
| Nov-94 | 5.61 | 5.91 | 5.60 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dec-94 | 5.97 | 6.06 | 5.97 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jan-95 | 6.64 | 6.12 | 6.63 | 0.00 | 0.00 | 0.00 | 0.00 |
| Feb-95 | 6.39 | 6.13 | 6.39 | 0.00 | 0.00 | 0.00 | 0.01 |
| Mar-95 | 7.02 | 6.13 | 7.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| Apr-95 | 6.19 | 6.10 | 6.19 | 0.00 | 0.00 | 0.00 | 0.00 |
| May-95 | 7.17 | 6.16 | 6.96 | 0.06 | 0.11 | 0.03 | 0.20 |
| Jun-95 | 5.80 | 6.15 | 5.80 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jul-95 | 5.90 | 6.18 | 5.90 | 0.00 | 0.00 | 0.00 | 0.00 |
| Aug-95 | 5.52 | 6.13 | 5.52 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sep-95 | 5.51 | 6.11 | 5.50 | 0.00 | 0.00 | 0.00 | 0.00 |
| Oct-95 | 6.00 | 6.14 | 6.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Nov-95 | 6.09 | 6.18 | 6.09 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dec-95 | 6.10 | 6.19 | 6.09 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jan-96 | 5.21 | 6.07 | 5.21 | 0.00 | 0.00 | 0.00 | 0.00 |
| Feb-96 | 3.76 | 5.85 | 3.76 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mar-96 | 6.55 | 5.82 | 6.55 | 0.00 | 0.00 | 0.00 | 0.00 |
| Apr-96 | 6.92 | 5.88 | 6.89 | 0.00 | 0.00 | 0.04 | 0.04 |
| May-96 | 6.26 | 5.80 | 6.26 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jun-96 | 5.80 | 5.80 | 5.80 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jul-96 | 6.67 | 5.86 | 6.67 | 0.00 | 0.00 | 0.00 | 0.00 |
| Aug-96 | 5.39 | 5.85 | 5.39 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sep-96 | 5.73 | 5.87 | 5.67 | 0.00 | 0.03 | 0.03 | 0.06 |
| Oct-96 | 5.72 | 5.85 | 5.72 | 0.00 | 0.00 | 0.00 | 0.00 |
| Nov-96 | 5.37 | 5.79 | 5.37 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dec-96 | 7.17 | 5.88 | 7.17 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jan-97 | 6.33 | 5.97 | 6.33 | 0.00 | 0.00 | 0.00 | 0.00 |
| Feb-97 | 7.78 | 6.31 | 7.78 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mar-97 | 7.30 | 6.37 | 7.30 | 0.00 | 0.00 | 0.00 | 0.00 |
| Apr-97 | 6.92 | 6.37 | 6.92 | 0.00 | 0.00 | 0.00 | 0.00 |
| May-97 | 7.03 | 6.43 | 7.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jun-97 | 6.88 | 6.52 | 6.88 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jul-97 | 6.62 | 6.52 | 6.62 | 0.00 | 0.00 | 0.00 | 0.00 |
| Aug-97 | 5.67 | 6.54 | 5.67 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sep-97 | 5.90 | 6.56 | 5.54 | 0.26 | 0.11 | 0.00 | 0.36 |
| Oct-97 | 5.84 | 6.57 | 5.83 | 0.00 | 0.00 | 0.01 | 0.01 |
| Nov-97 | 5.53 | 6.58 | 5.50 | 0.00 | 0.00 | 0.03 | 0.03 |
| Dec-97 | 4.89 | 6.39 | 4.89 | 0.00 | 0.00 | 0.00 | 0.00 |

## Table 4 - Water Production History at Clark Springs



| | Monthly Water Production from Clark Springs in cfs | | | | | | |
|---|---|---|---|---|---|---|---|
| | Total and Average | | Production from each Facility | | | | |
| Month and Year | Combined Total | 1-Year Running Average | Gallery | Well 1 | Well 2 | Well 3 | Total Wells |
| Jan-98 | 5.69 | 6.34 | 5.68 | 0.00 | 0.00 | 0.00 | 0.00 |
| Feb-98 | 6.23 | 6.21 | 5.41 | 0.14 | 0.22 | 0.47 | 0.83 |
| Mar-98 | 7.96 | 6.26 | 7.96 | 0.00 | 0.00 | 0.00 | 0.00 |
| Apr-98 | 6.86 | 6.26 | 6.86 | 0.00 | 0.00 | 0.00 | 0.00 |
| May-98 | 5.84 | 6.16 | 5.80 | 0.00 | 0.00 | 0.04 | 0.04 |
| Jun-98 | 6.61 | 6.14 | 6.52 | 0.00 | 0.00 | 0.09 | 0.09 |
| Jul-98 | 5.63 | 6.05 | 5.46 | 0.00 | 0.00 | 0.17 | 0.17 |
| Aug-98 | 5.95 | 6.08 | 5.81 | 0.06 | 0.00 | 0.08 | 0.15 |
| Sep-98 | 5.14 | 6.01 | 1.38 | 0.00 | 0.46 | 3.29 | 3.75 |
| Oct-98 | 4.40 | 5.89 | 0.11 | 0.00 | 1.35 | 2.94 | 4.29 |
| Nov-98 | 5.39 | 5.88 | 4.61 | 0.00 | 0.23 | 0.55 | 0.78 |
| Dec-98 | 7.83 | 6.13 | 0.00 | 1.86 | 0.00 | 6.44 | 8.30 |
| Jan-99 | 7.54 | 6.28 | 0.00 | 1.49 | 0.59 | 6.06 | 8.14 |
| Feb-99 | 7.20 | 6.36 | 0.64 | 0.15 | 2.01 | 4.40 | 6.56 |
| Mar-99 | 8.38 | 6.40 | 0.00 | 0.99 | 2.64 | 5.07 | 8.70 |
| Apr-99 | 8.15 | 6.50 | 0.00 | 1.14 | 2.61 | 4.44 | 8.19 |
| May-99 | 5.82 | 6.50 | 1.17 | 0.00 | 1.54 | 3.11 | 4.65 |
| Jun-99 | 7.24 | 6.56 | 2.35 | 0.00 | 0.65 | 4.25 | 4.90 |
| Jul-99 | 6.56 | 6.63 | 2.81 | 0.00 | 0.11 | 3.63 | 3.75 |
| Aug-99 | 6.56 | 6.68 | 2.44 | 0.00 | 0.00 | 4.11 | 4.11 |
| Sep-99 | 6.15 | 6.77 | 2.54 | 0.00 | 0.00 | 3.60 | 3.60 |
| Oct-99 | 5.59 | 6.87 | 2.49 | 0.00 | 0.00 | 3.10 | 3.10 |
| Nov-99 | 5.57 | 6.88 | 0.38 | 0.05 | 1.16 | 3.98 | 5.19 |
| Dec-99 | 7.66 | 6.87 | 0.08 | 1.35 | 1.76 | 4.48 | 7.59 |
| Jan-00 | 6.14 | 6.75 | 6.14 | 0.00 | 0.00 | 0.00 | 0.00 |
| Feb-00 | 5.74 | 6.63 | 5.72 | 0.02 | 0.00 | 0.00 | 0.02 |
| Mar-00 | 5.77 | 6.41 | 5.77 | 0.00 | 0.00 | 0.00 | 0.00 |
| Apr-00 | 6.41 | 6.27 | 6.41 | 0.00 | 0.00 | 0.00 | 0.00 |
| May-00 | 7.00 | 6.37 | 7.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jun-00 | 6.15 | 6.27 | 6.15 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jul-00 | 4.55 | 6.11 | 4.55 | 0.00 | 0.00 | 0.00 | 0.00 |
| Aug-00 | 6.00 | 6.06 | 6.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sep-00 | 5.25 | 5.99 | 5.19 | 0.06 | 0.00 | 0.00 | 0.06 |
| Oct-00 | 1.32 | 5.63 | 1.32 | 0.00 | 0.00 | 0.00 | 0.00 |
| Nov-00 | 1.05 | 5.25 | 1.05 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dec-00 | 2.02 | 4.78 | 2.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jan-01 | 2.16 | 4.45 | 2.16 | 0.00 | 0.00 | 0.00 | 0.01 |
| Feb-01 | 4.10 | 4.31 | 4.09 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mar-01 | 4.52 | 4.21 | 4.51 | 0.00 | 0.00 | 0.00 | 0.00 |
| Apr-01 | 4.04 | 4.01 | 4.04 | 0.00 | 0.00 | 0.00 | 0.01 |
| May-01 | 4.09 | 3.77 | 4.09 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jun-01 | 4.41 | 3.63 | 4.41 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jul-01 | 4.03 | 3.58 | 4.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| Aug-01 | 4.00 | 3.42 | 4.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sep-01 | 3.53 | 3.27 | 3.52 | 0.00 | 0.00 | 0.00 | 0.00 |
| Oct-01 | 3.11 | 3.42 | 3.11 | 0.00 | 0.00 | 0.00 | 0.00 |
| Nov-01 | 3.11 | 3.59 | 3.11 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dec-01 | 4.61 | 3.81 | 4.61 | 0.00 | 0.00 | 0.00 | 0.00 |

## *Vicinity Map*
### *Rock Creek Catchment*

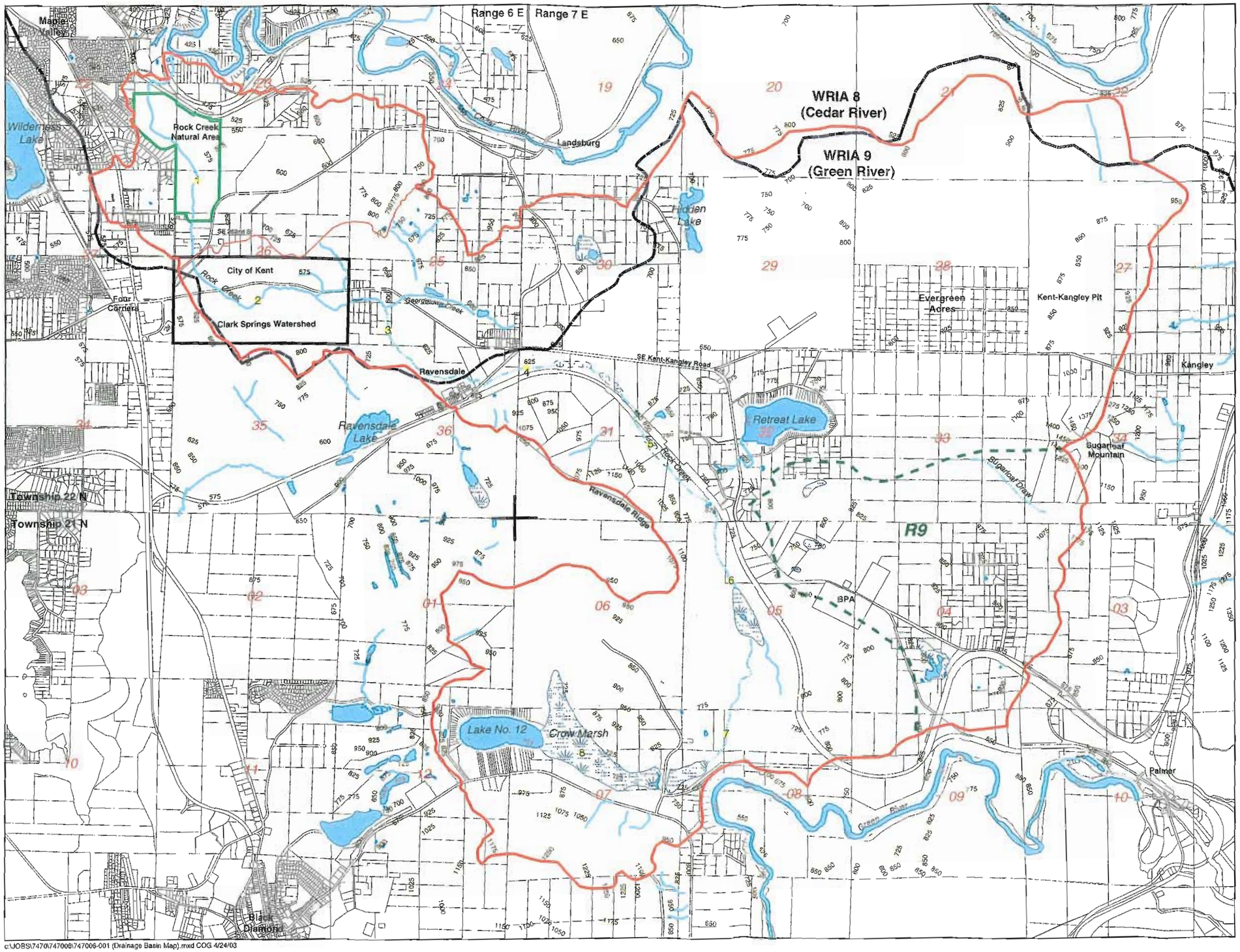



747006AA.CDR HEL 5/1/03

HARTCROWSER
7470-06
4/03
Figure 1

*This page intentionally left blank.*

# Drainage Basin Map
## Rock Creek Catchment




c:\JOBS\7470\747006\747006-001 (Drainage Basin Map).mxd COG 4/24/03

## Legend

- Rock Creek Mile Marker
- Rock Creek Catchment Boundary
- Boundary between upper and lower Catchment
- Surveyed Stream
- Intermittent Stream
- Clark Springs Watershed
- Rock Creek Natural Area
- Wetland (Undelineated)
- Wetland (Delineated by King County)
- Surface Water Body
- Elevation Contour in Feet
- Parcel Boundary
- Boundary Between WRIA 8 & WRIA 9 (Department of Ecology)
- Approximate Area of Sub-Basin R9 *

Notes:

1) Parcel coverage based on King County GIS database dated March 2000 provided by City of Kent.

2) Base map data provided by Triathalon at scale 1:24,000 dated April 2001.

* Approximate area of sub basin R9 that was excluded from King County (1993) drainage area estimates.

N

0 1000 2000 4000 6000

Units in Feet
Scale = 1:36000

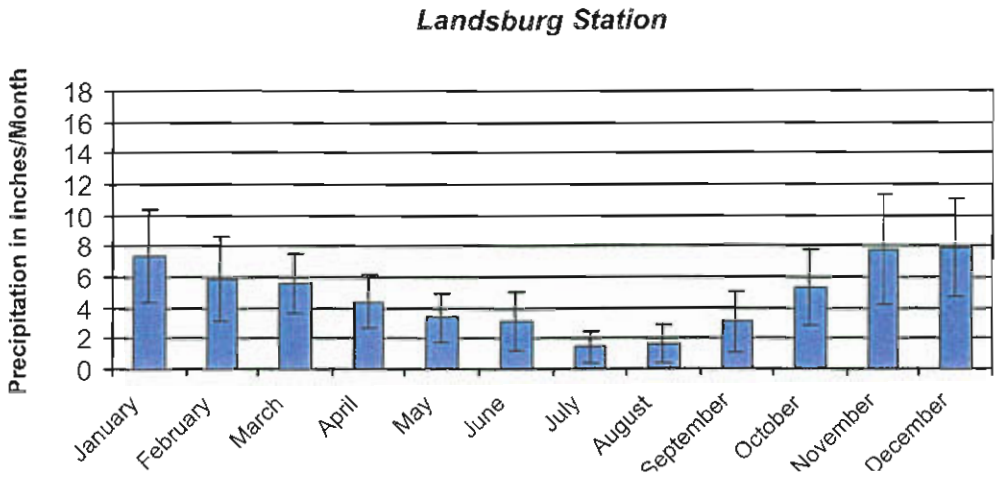
HARTCROWSER

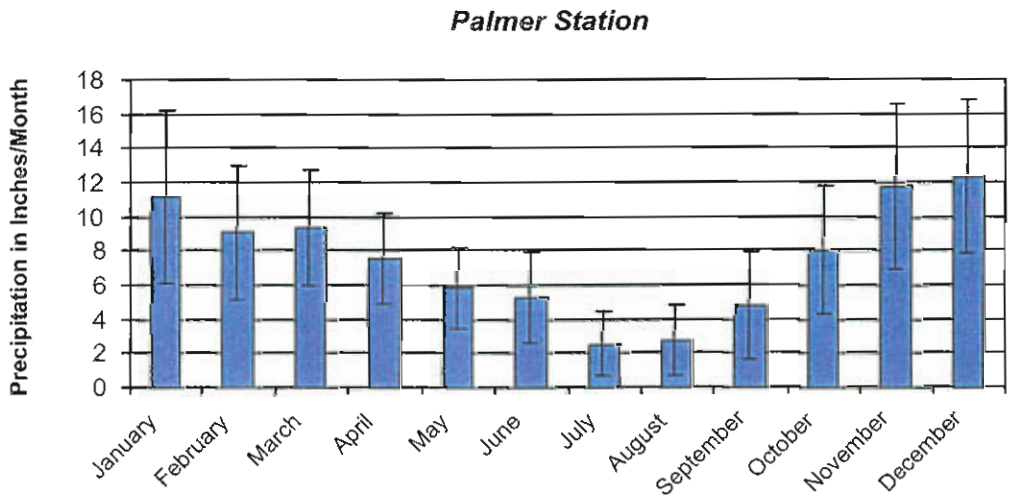
7470-06 4/03

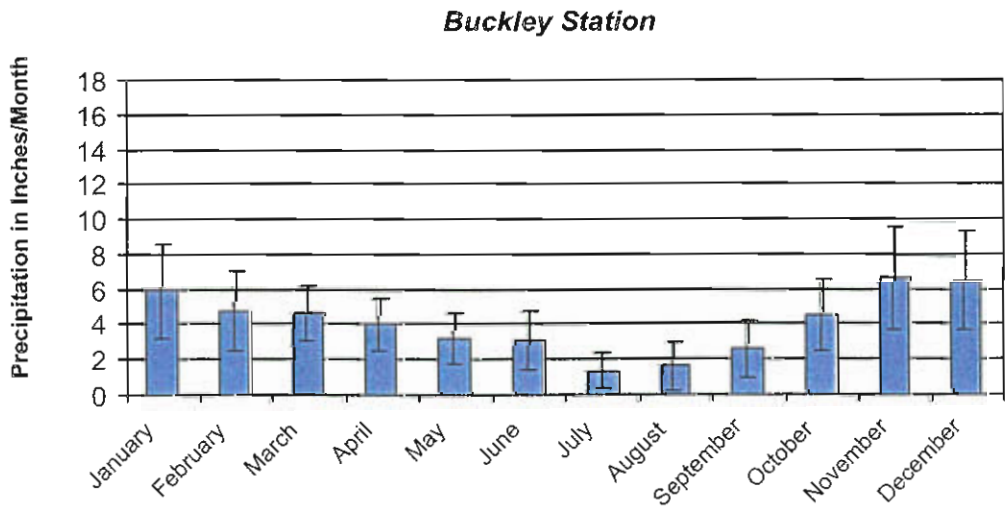
Figure 2

*This page intentionally left blank.*

# Variation in Mean Monthly Precipitation




Note: Figures show monthly mean and one standard deviation, for the data record from 1932 through 2001. Data from Western Regional Climate Center.

747006BG.CDR DNK 4/23/03

HARTCROWSER

7470-06 4/03

Figure 3

*This page intentionally left blank.*

## Distribution of Mean Annual Precipitation
### Rock Creek Catchment

c:\jobs\7470\747006\747006-003 (Dist of Mean Annual Precip).mxd COG 4/24/03

**Legend**

- Rock Creek Catchment Boundary
- Boundary between upper and lower Catchments
- Clark Springs Watershed
- Rock Creek Natural Area
- Surveyed Stream
- Intermittent Stream
- Wetland (Undelineated)
- Wetland (Delineated by King County)
- Surface Water Body
- Elevation Contour in Feet
- Parcel Boundary
- 48-52 inches per year
- 52-56 inches per year
- 56-60 inches per year
- 60-70 inches per year
- 70-80 inches per year
- 80-90 inches per year

Notes:

1) Parcel coverage based on King County GIS database dated March 2000 provided by City of Kent.

2) Base map data provided by Triathalon at scale 1:24,000 dated April 2001.

N

0 1000 2000 4000 6000

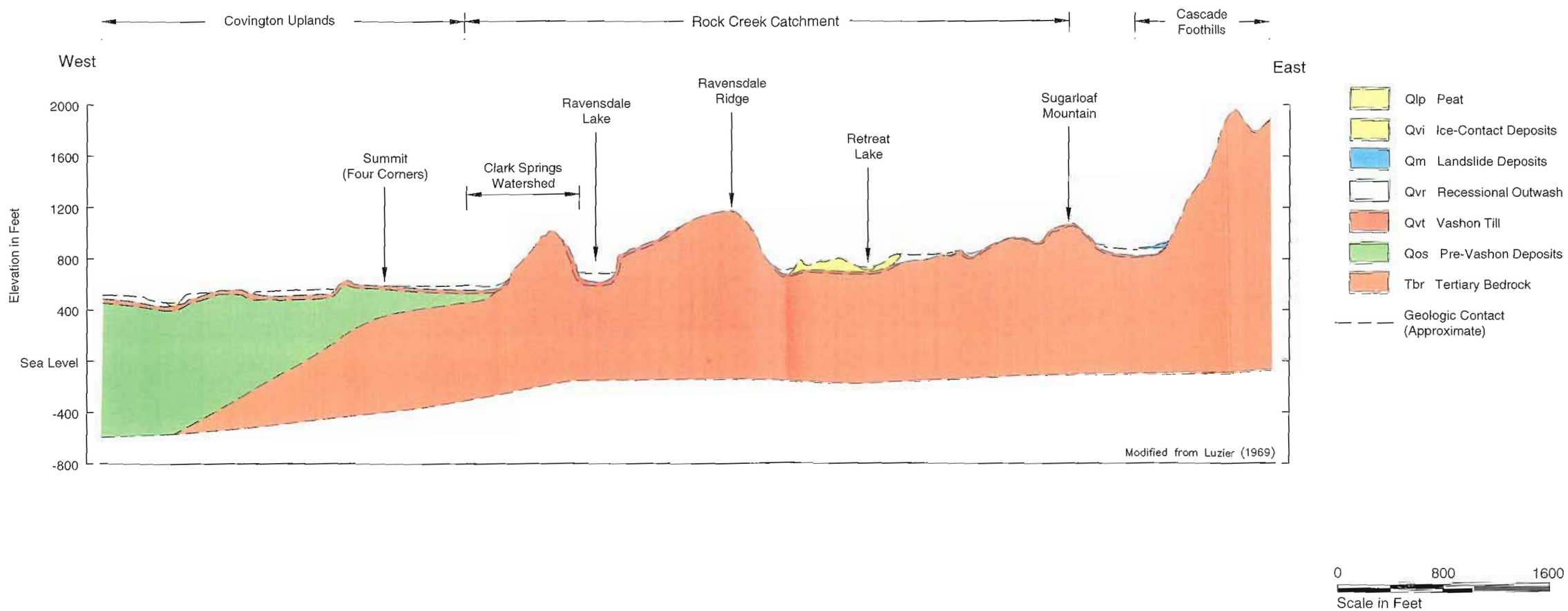
Units in Feet
Scale = 1:36000

HARTCROWSER

7470-06 4/03

Figure 4

## *Conceptual Regional Geologic Cross Section*
### *Rock Creek Catchment*



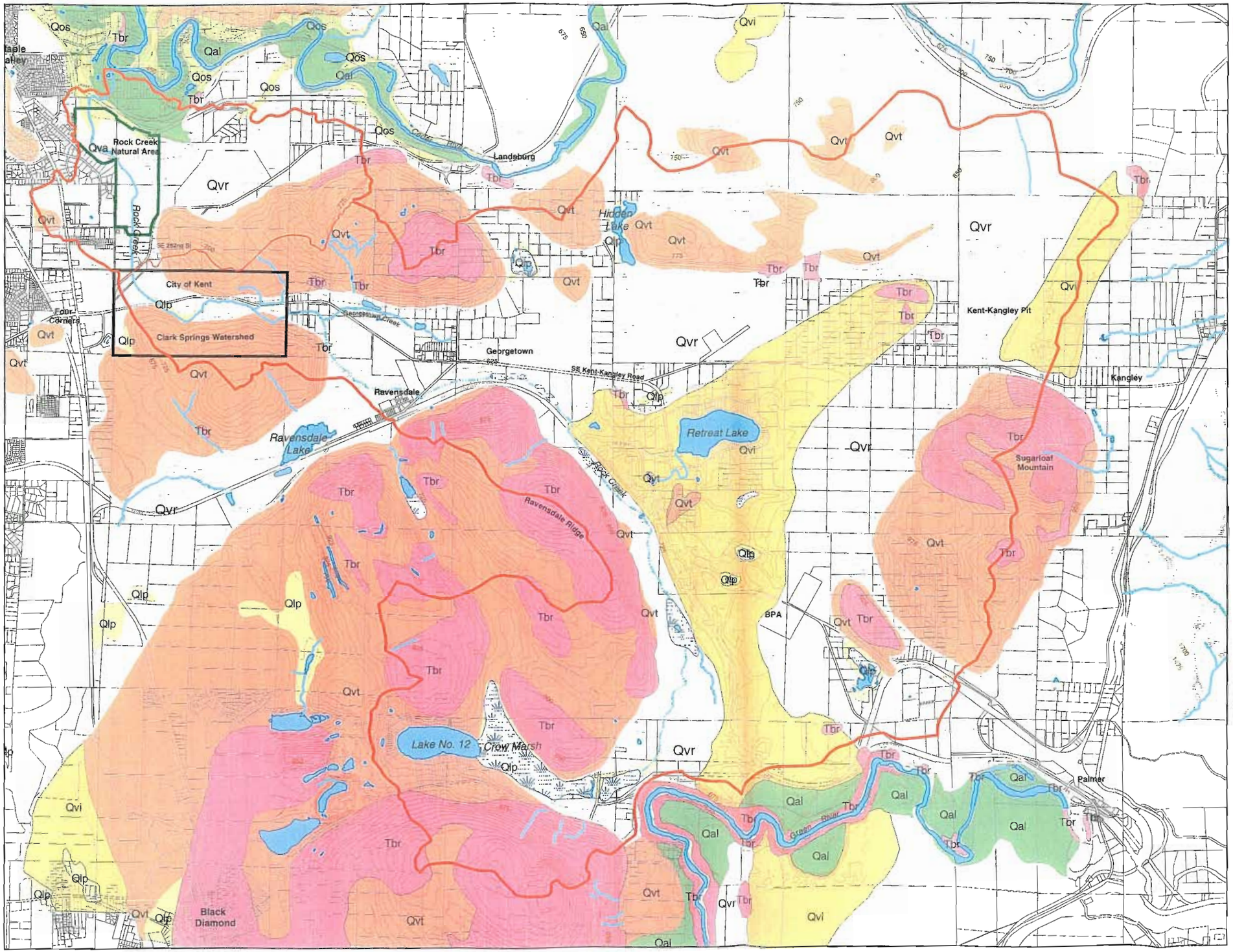

74700628.DWG HEL 5/1/03

HARTCROWSER

7470-06 4/03

Figure 5

# Detailed Geology Map
## Rock Creek Catchment




## Legend

- Rock Creek Catchment Boundary
- Boundary between upper and lower Catchments
- Clark Springs Watershed
- Rock Creek Natural Area
- Surveyed Stream
- Intermittent Stream
- Wetland (Undelineated)
- Wetland (Delineated by King County)
- Surface Water Body
- Surface Contour in Feet
- Parcel Boundary
- Qal - Alluvium
- Qlp - Peat
- Qvr - Recessional Outwash
- Qvi - Ice-Contact Deposits
- Qvt - Vashon Till
- Qva - Advance Outwash
- Qos - Pre-Vashon Deposits
- Tbr - Tertiary Bedrock

Notes:

1) Parcel coverage based on King County GIS database dated March 2000 provided by City of Kent.

2) Base map data provided by Triathalon at scale 1:24,000 dated April 2001.

N

0 1000 2000 4000 6000

Units in Feet
Scale = 1:36000

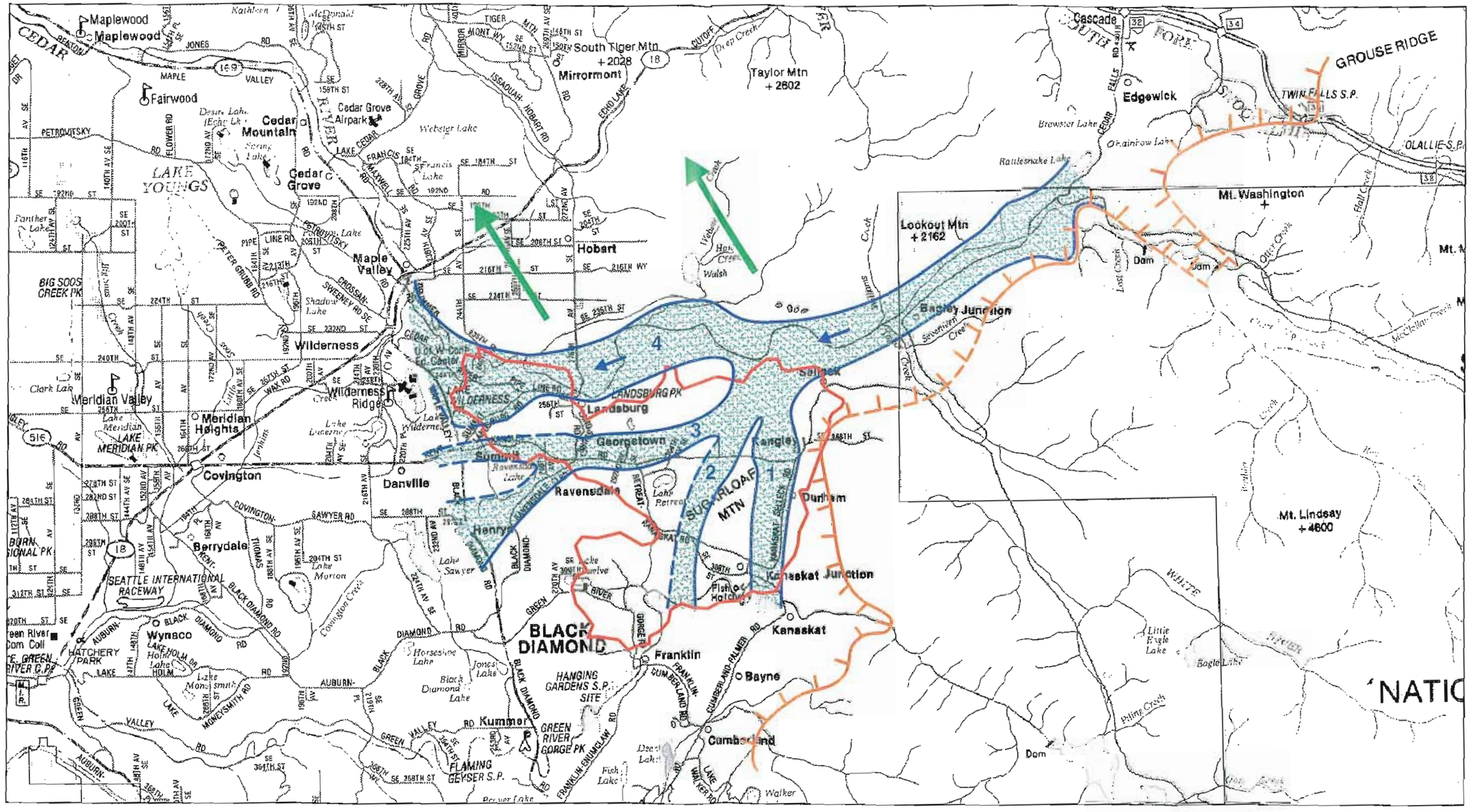
HARTCROWSER

7470-06 4/03

Figure 6

c:\JOBS\7470\747006\747006-002 (Detailed Geology Map).mxd COG 4/24/03

## *Glacial Retreat in Southeast Puget Sound*




Rock Creek Catchment Boundary

Inferred Sequence of Glacial Outwash Channels in Rock Creek Basin Area

Direction of Ice Marginal Meltwater Outflow

Maximum Southeasterly Extent of Vashon Glaciation (Puget Lobe)

Progressive Retreat of Puget Lobe

N

0 10,000 20,000

Approximate Scale in Feet

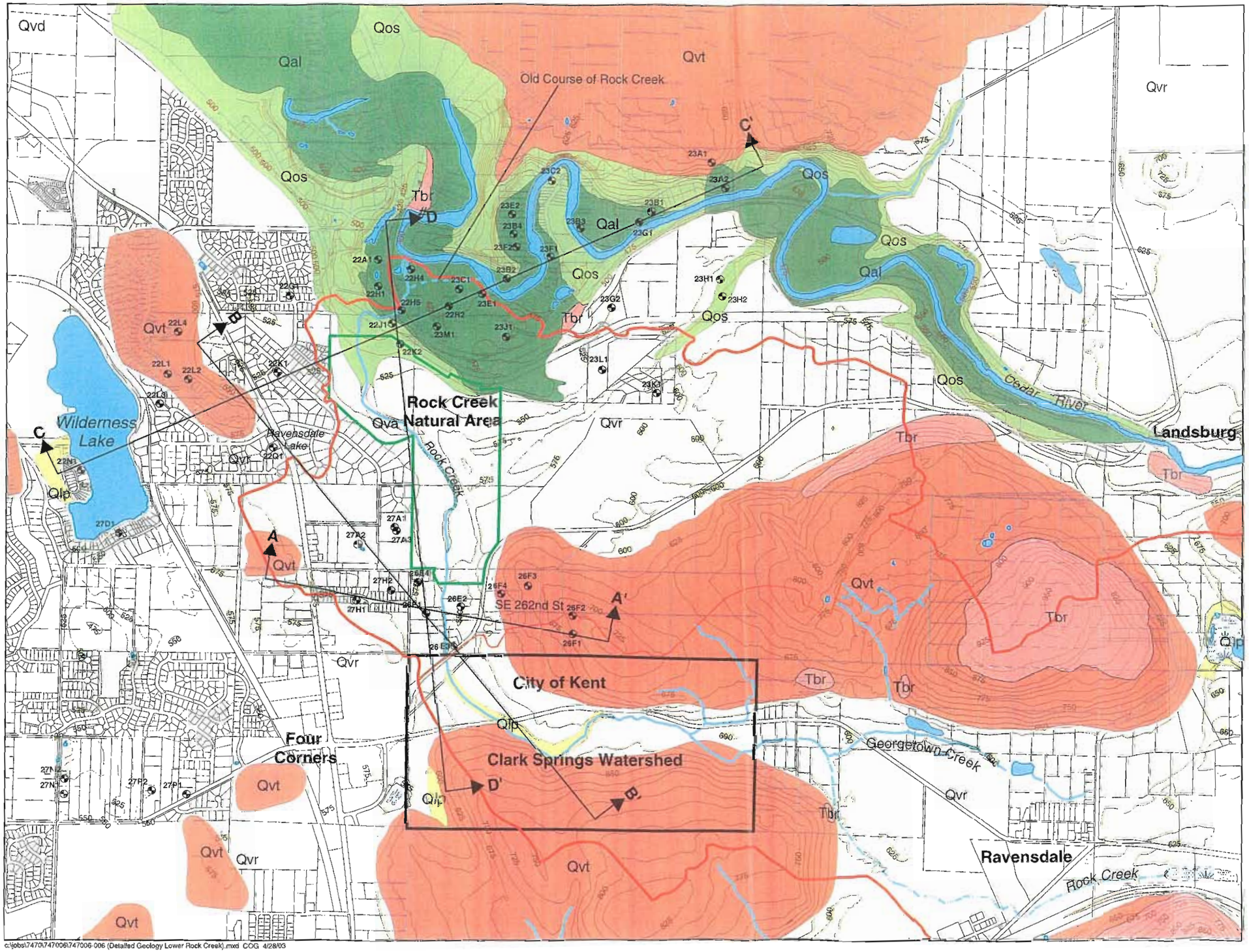
HARTCROWSER

7470-06 4/03

Figure 7

74700629.DWG HEL 5/1/03

## Detailed Geology Map
## Lower Rock Creek Catchment




c:\jobs\7470\747006\747006-006 (Detailed Geology Lower Rock Creek).mxd COG 4/28/03

### Legend

- Rock Creek Catchment Boundary
- Boundary between upper and lower Catchments
- Clark Springs Watershed
- Rock Creek Natural Area
- Surveyed Stream
- Intermittent Stream
- Wetland (Undelineated)
- Wetland (Delineated by King County)
- Surface Water Body
- 775 Elevation Contour in Feet
- Parcel Boundary
- Qal - Alluvium
- Qlp - Peat
- Qvr - Recessional Outwash
- Qvi - Ice-Contact Deposits
- Qvt - Vashon Till
- Qva - Advance Outwash
- Qos - Pre-Vashon Deposite
- Tbr - Tertiary Bedrock
- A A' Cross Section Location and Designation
- 22A1 Well Location and Number

Notes:

1) Parcel coverage based on King County GIS database dated March 2000 provided by City of Kent.

2) Base map data provided by Triathalon at scale 1:24,000 dated April 2001.

N

0 500 1000 2000 3000

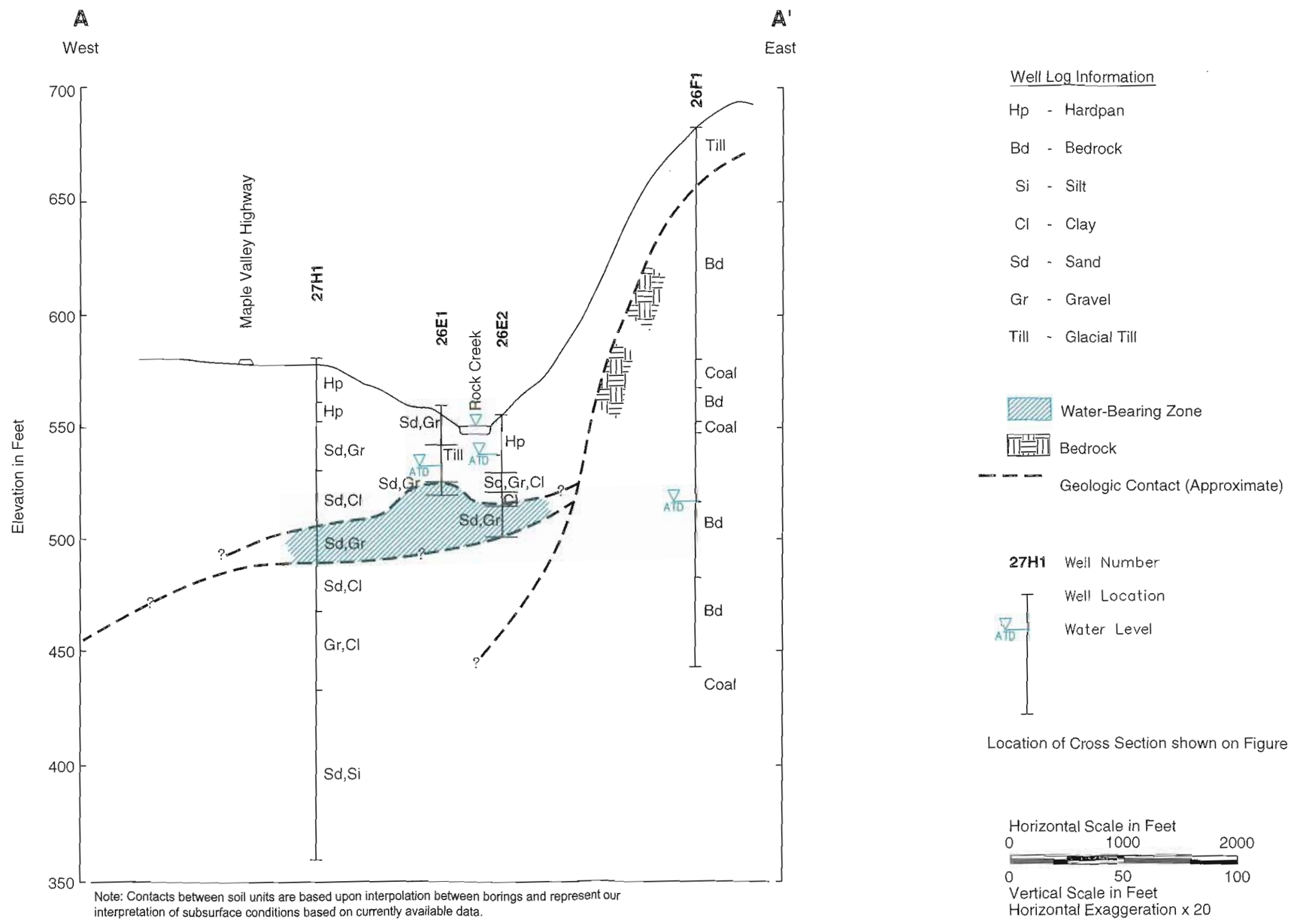
Units in Feet
Scale = 1:18000

HARTCROWSER

7470-06 4/03

Figure 8

## *Generalized Geologic Cross Section A-A'*
***Lower Rock Creek***




Note: Contacts between soil units are based upon interpolation between borings and represent our interpretation of subsurface conditions based on currently available data.

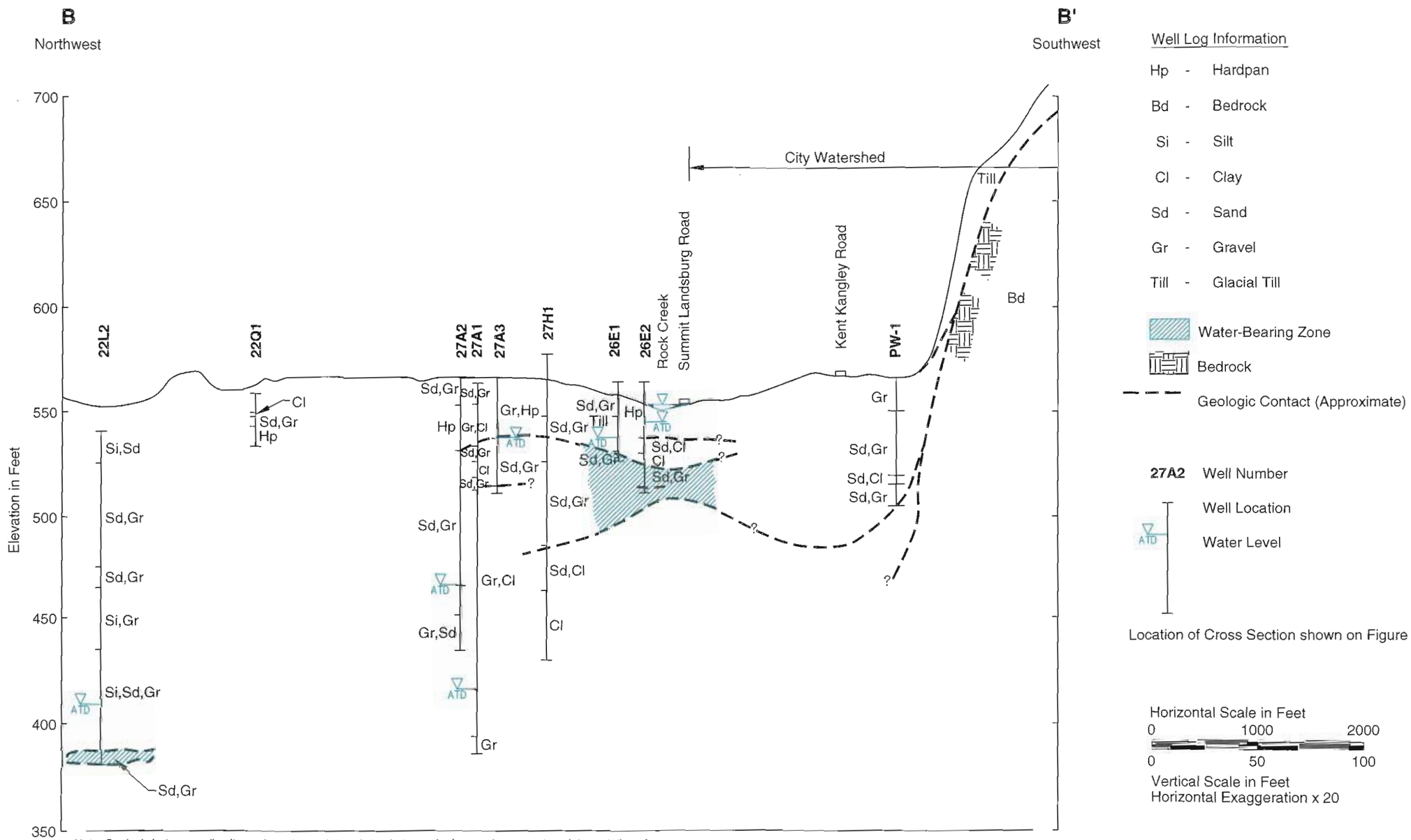
7470\0624.DWG HEL 5/1/03

HARTCROWSER

*7470-06* *4/03*

*Figure 9*

## *Generalized Geologic Cross Section B-B'*
### *Lower Rock Creek*




Note: Contacts between soil units are based upon interpolation between borings and represent our interpretation of subsurface conditions based on currently available data.

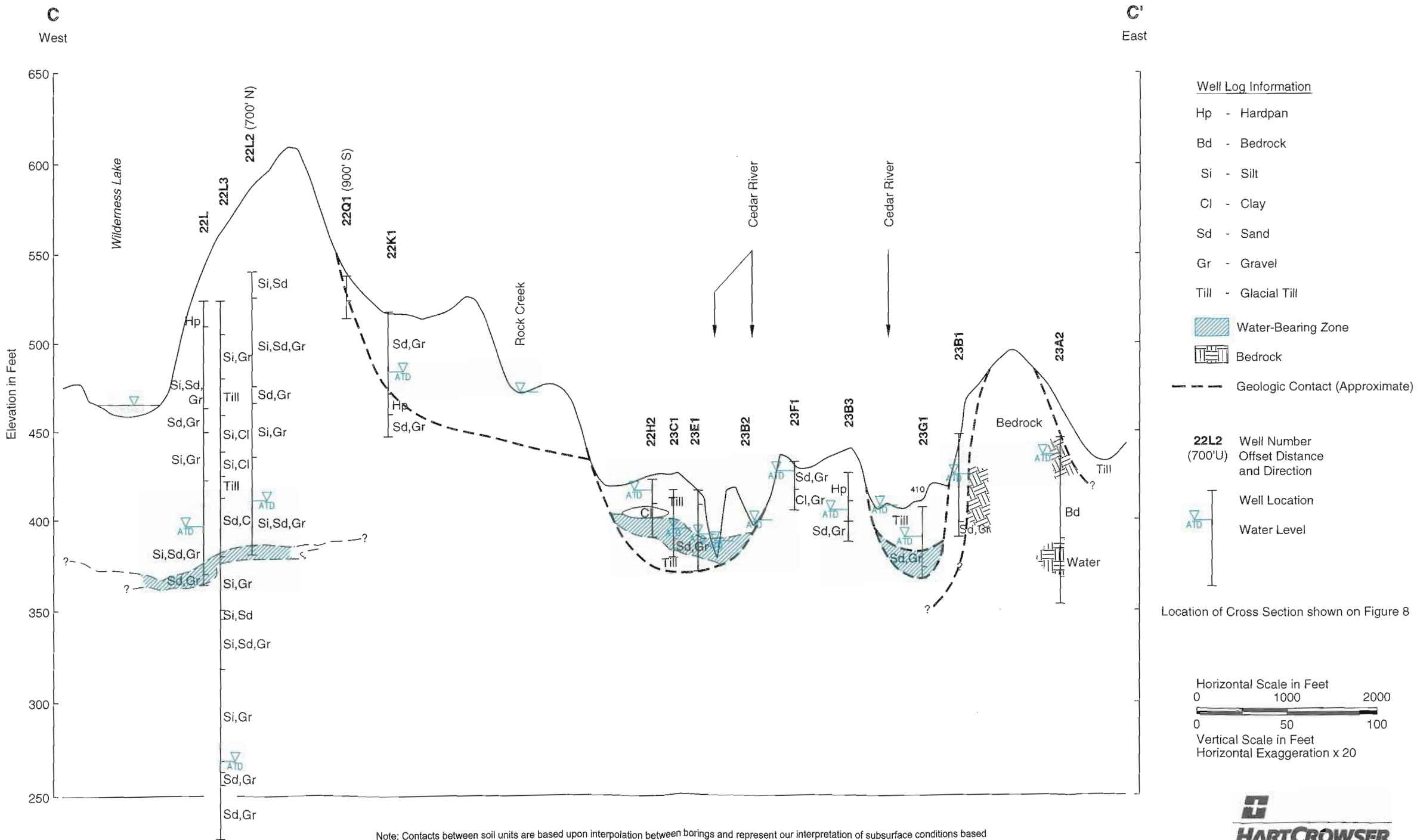
74700625.DWG HEL 5/1/03

HARTCROWSER

*7470-06* *4/03*

***Figure 10***

## *Generalized Geologic Cross Section C-C'*
### *Lower Rock Creek*




Note: Contacts between soil units are based upon interpolation between borings and represent our interpretation of subsurface conditions based on currently available data.

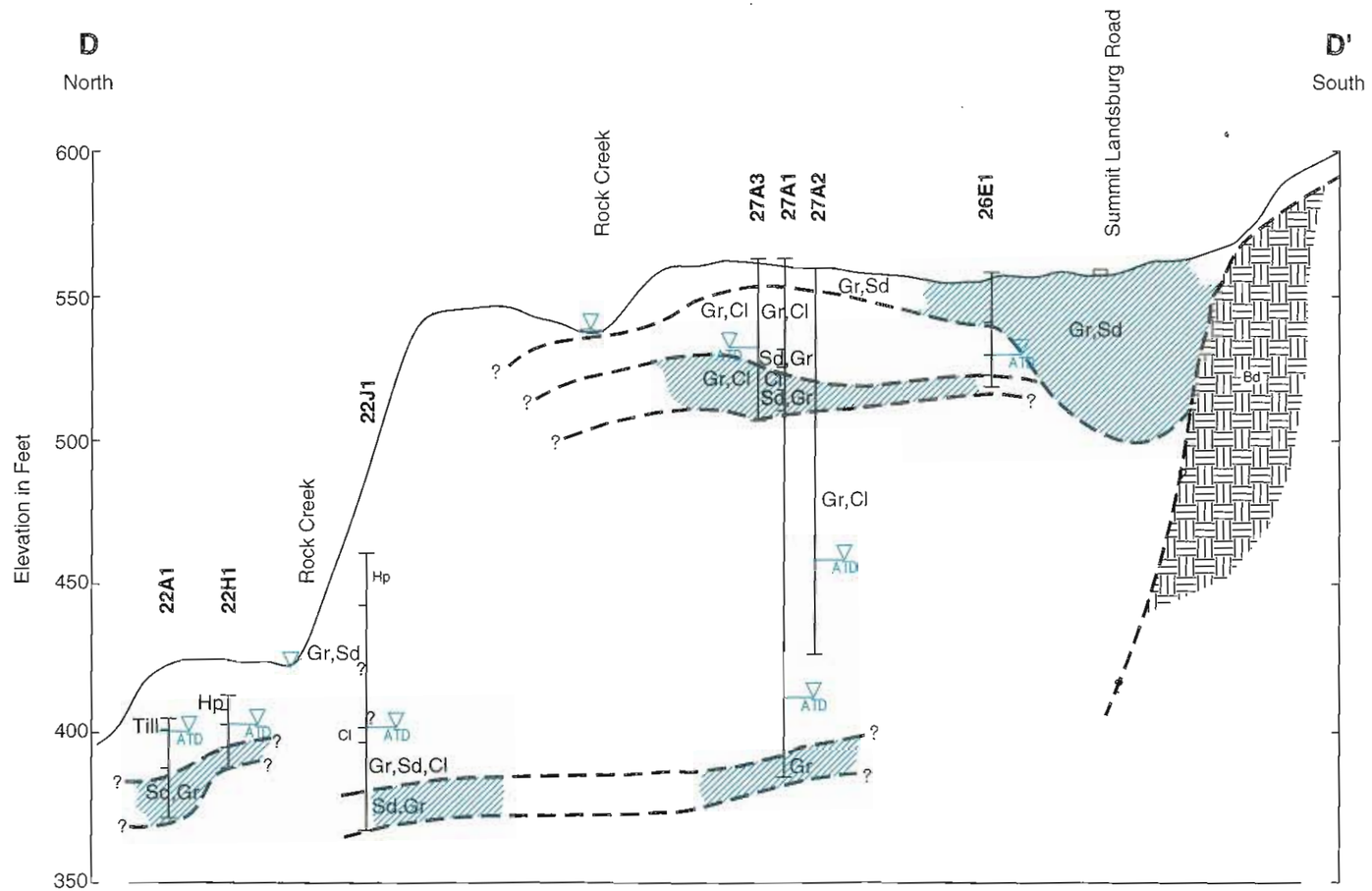
HARTCROWSER

*7470-06* *4/03*

***Figure 11***

7470\0626.DWG HEL 5/1/03

## *Generalized Geologic Cross Section D-D'*
### *Lower Rock Creek*




Note: Contacts between soil units are based upon interpolation between borings and represent our interpretation of subsurface conditions based on currently available data.

Well Log Information

Hp - Hardpan
Bd - Bedrock
Si - Silt
Cl - Clay
Sd - Sand
Gr - Gravel
Till - Glacial Till

Water-Bearing Zone
Bedrock
Geologic Contact (Approximate)

22A1 Well Number
Well Location
ATD Water Level

Location of Cross Section shown on Figure 8

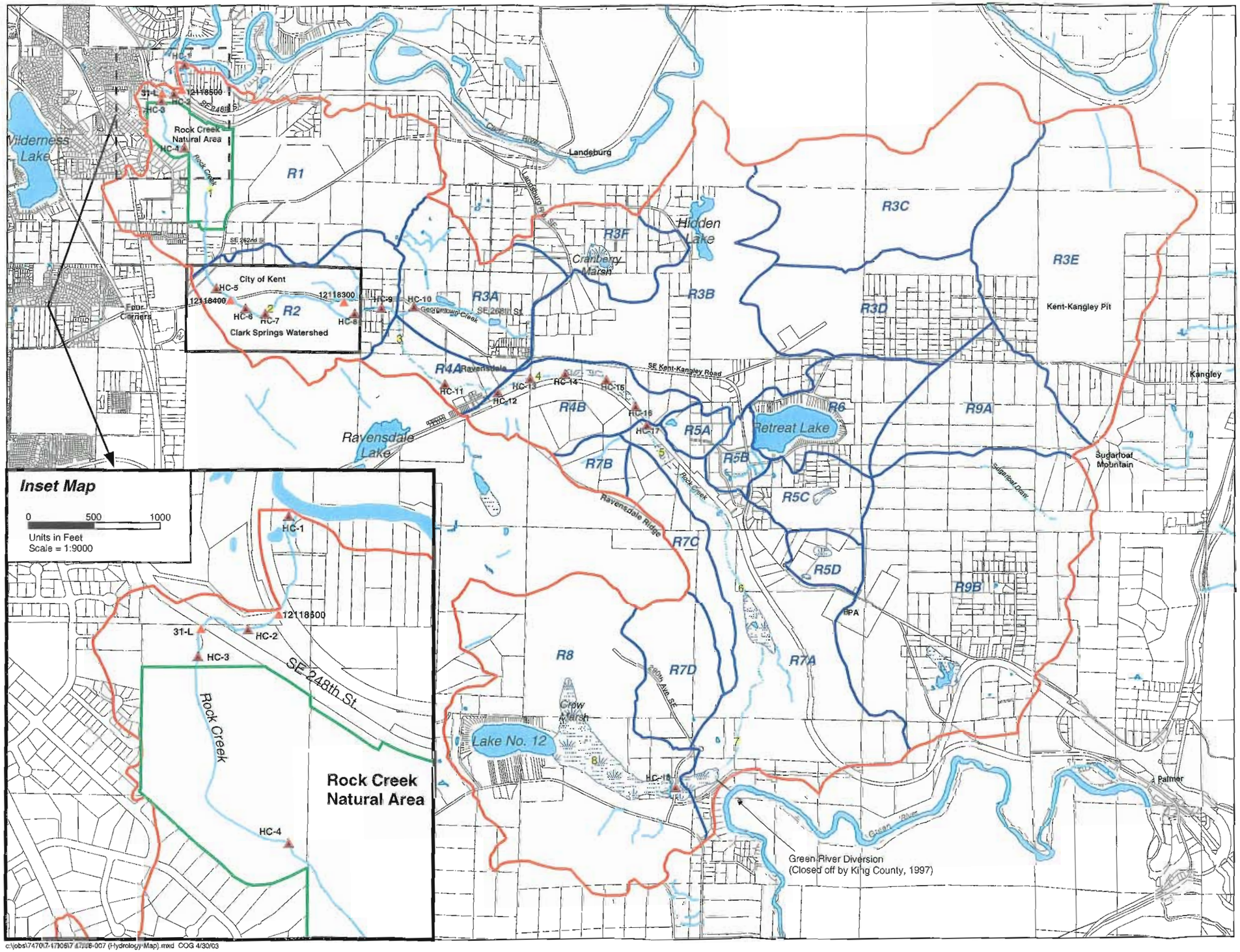
Horizontal Scale in Feet
0 1000 2000
0 50 100
Vertical Scale in Feet
Horizontal Exaggeration x 20

7470\0627.DWG HEL 5/1/03

HARTCROWSER
*7470-06* *4/03*
*Figure 12*

# Hydrology Map

## Rock Creek Catchment




## Legend

- Rock Creek Mile Marker
- R9A — Sub-Basin Boundary and Number
- Rock Creek Catchment Boundary
- Clark Springs Watershed
- Rock Creek Natural Area
- Surveyed Stream
- Intermittent Stream
- Wetland (Undelineated)
- Wetland (Delineated by King County)
- Surface Water Body
- Parcel Boundary
- 12118300 — Gaging Station Location and Number
- HC-7 — Manual Stream Flow Measurement Location and Number

Notes:

1) Parcel coverage based on King County GIS database dated March 2000 provided by City of Kent.

2) Base map data provided by Triathalon at scale 1:24,000 dated April 2001.

0 1000 2000 4000 6000
Units in Feet
Scale = 1:36000

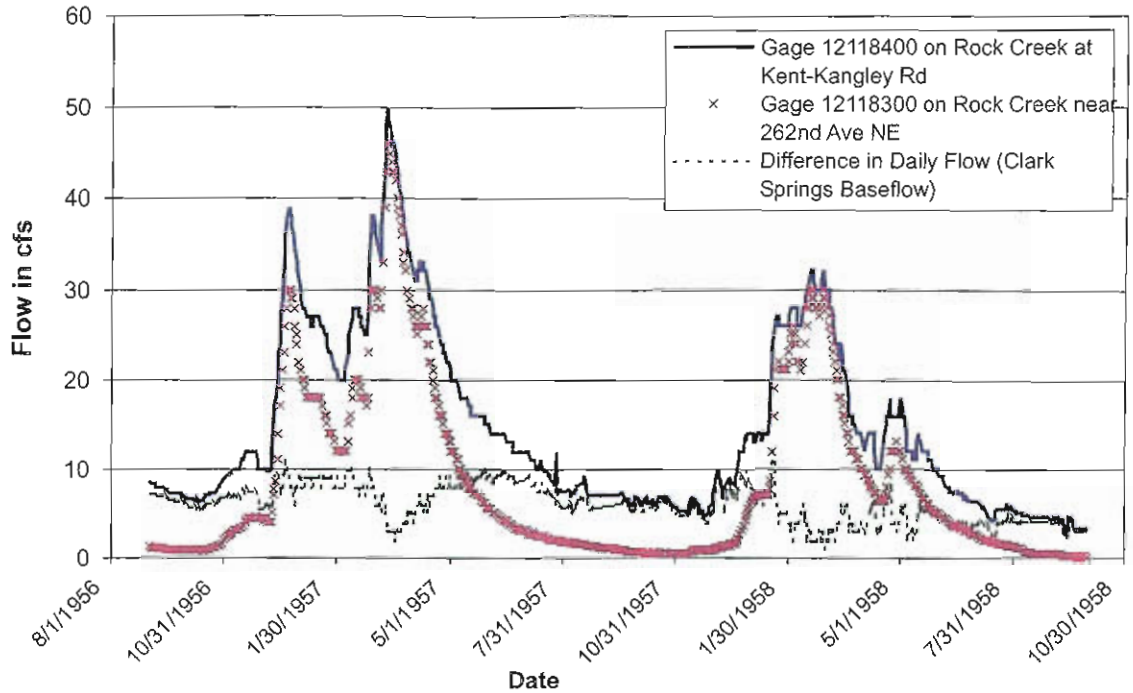
HARTCROWSER

7470-06 4/03

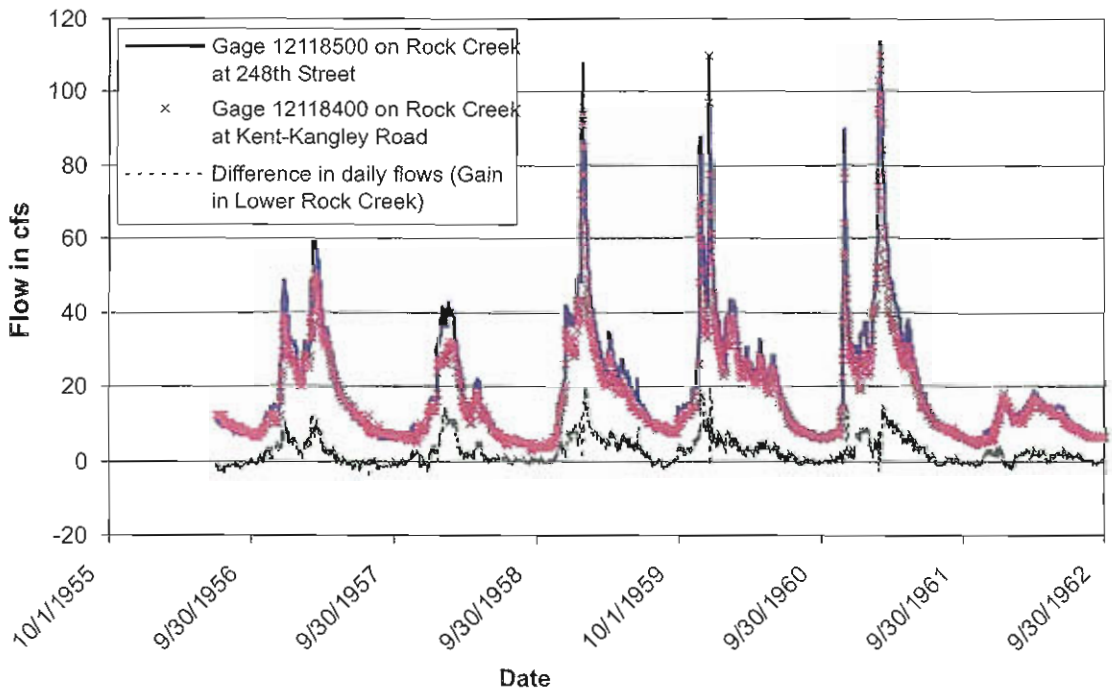
Figure 13

c:\jobs\7470\7-470\7-470B-007 (Hydrology Map).mxd COG 4/30/03

# *Rock Creek Streamflow Data*




a) Streamflow Data from Clark Springs Watershed




b) Streamflow Data for Lower Rock Creek

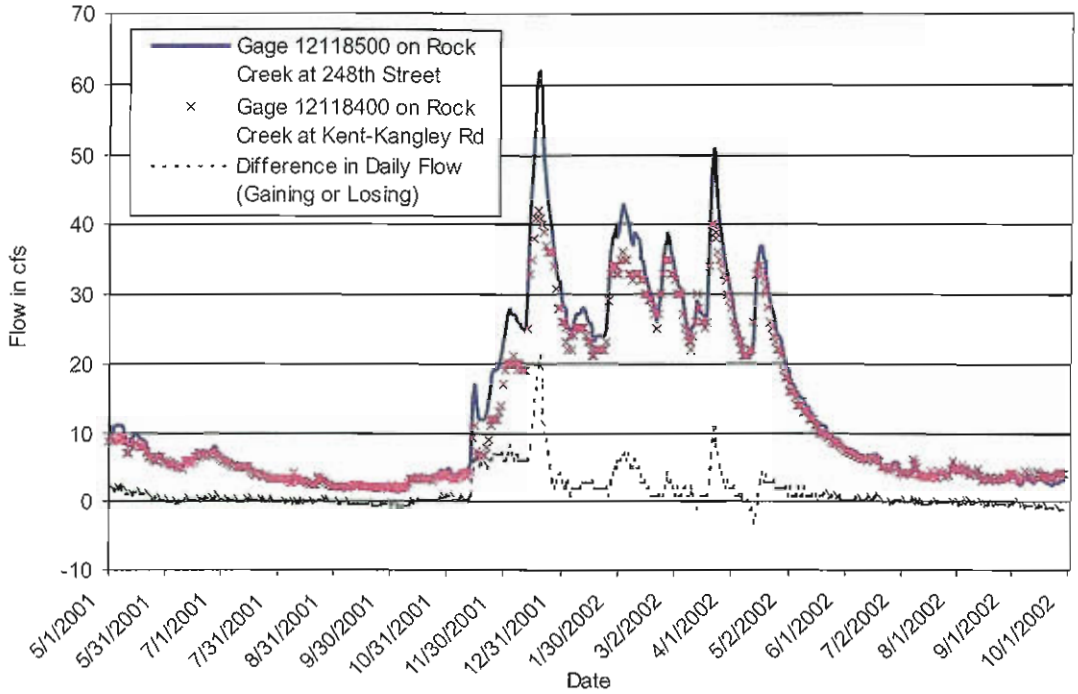
7470006E.cdr HEL 5/1/03

HARTCROWSER

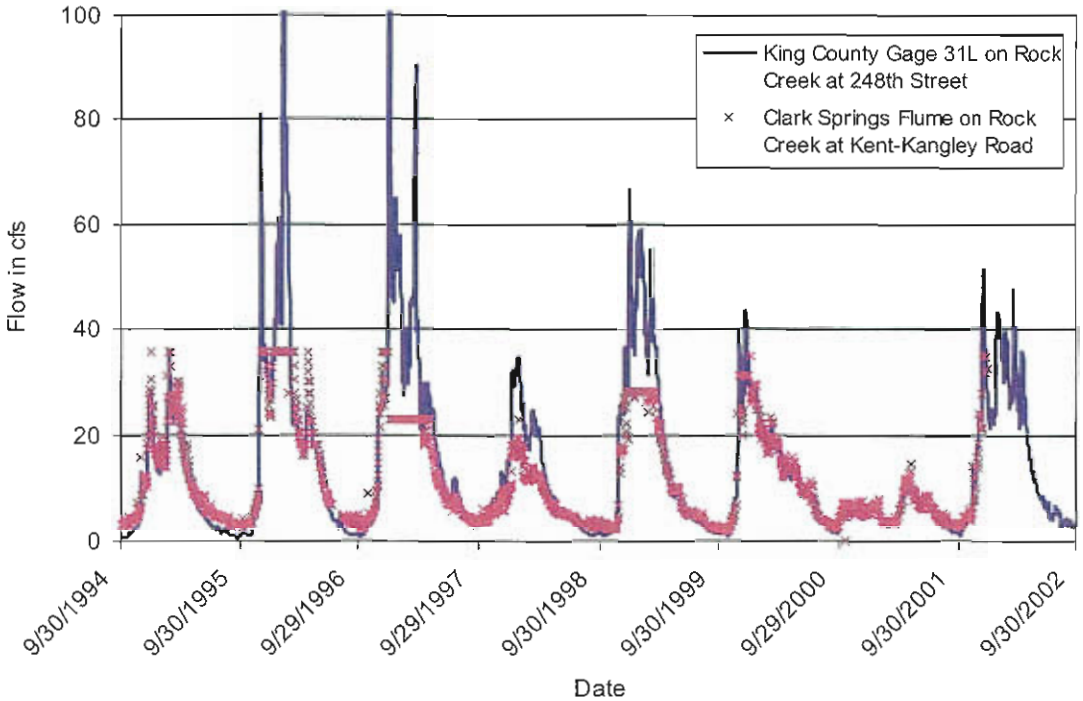
7470-06 4/03

Figure 14 1/2

# *Rock Creek Streamflow Data*




c) Recent USGS Streamflow Data from Lower Rock Creek. Data are provisional and subject to change




d) Streamflow Data for Lower Rock Creek, 1994 through 2002

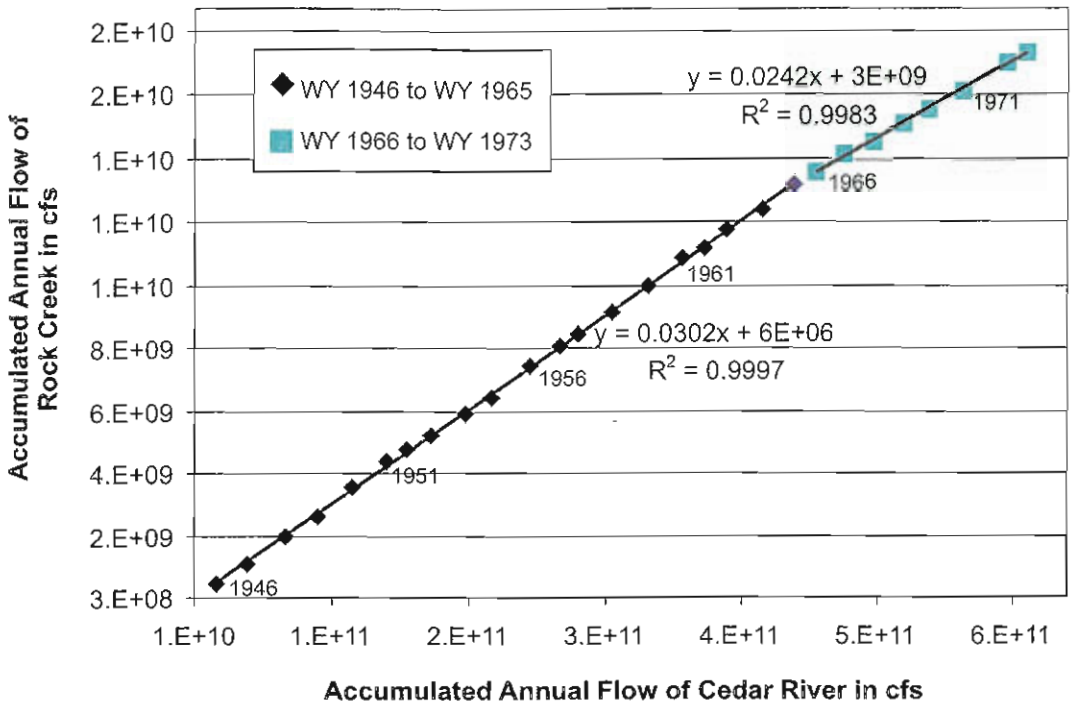
747006EE.cdr HEL 5/1/03

HARTCROWSER

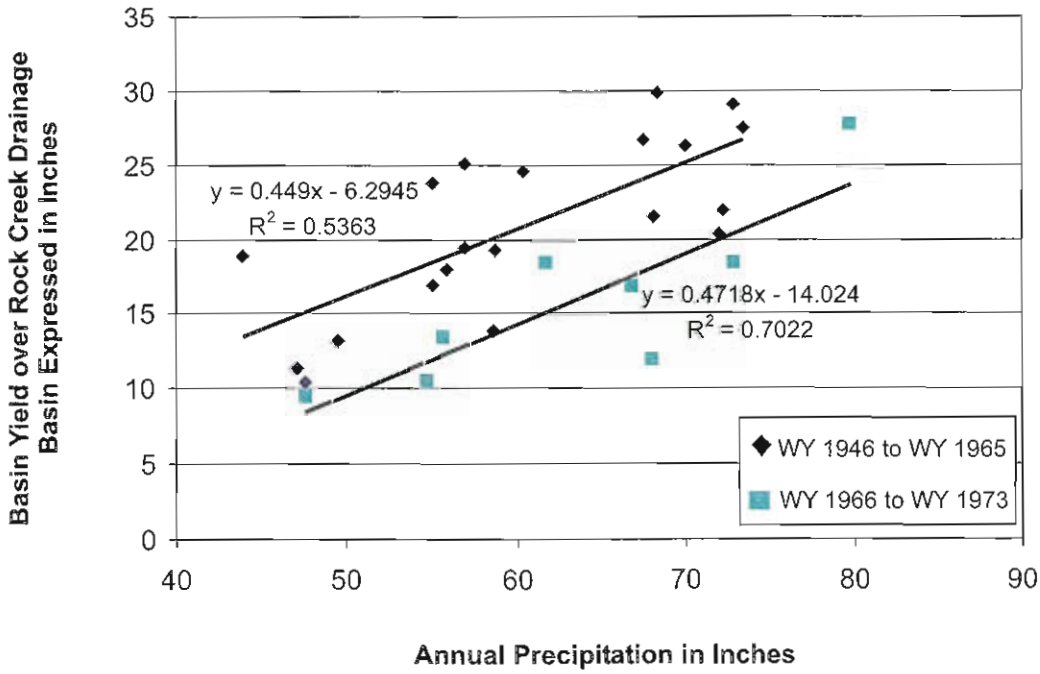
*7470-06* *4/03*

*Figure 14* *2/2*

## *Streamflow Analysis*
### *Rock Creek Catchment*




a) Double-Mass Curve of Rock Creek Flow versus Cedar River Flow at Renton
(USGS gage 12118500 versus USGS gage 12119000)



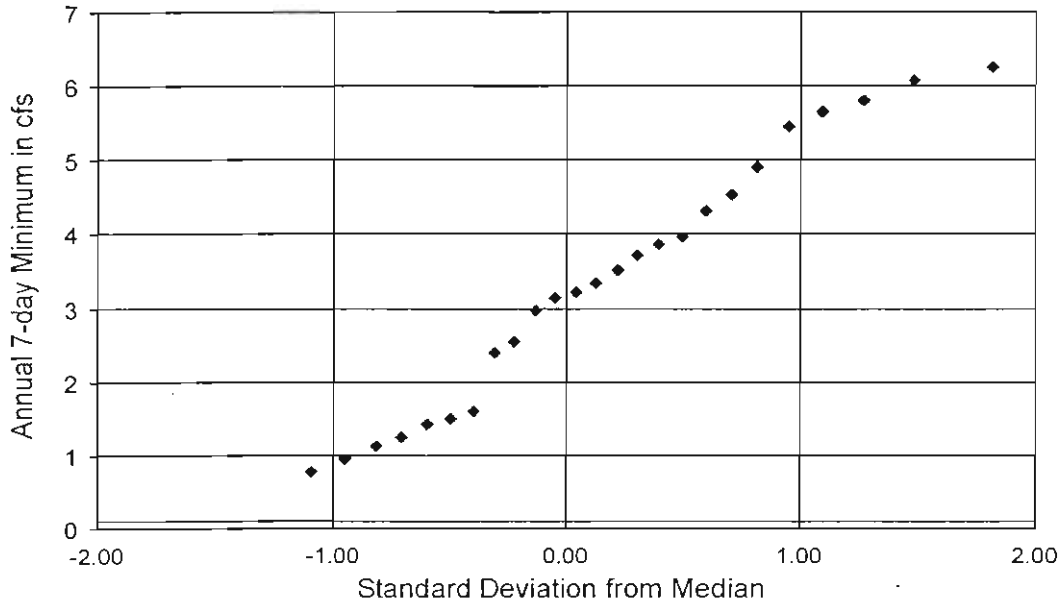

b) Correlation of Basin Yield versus Annual Precipitation

Note: Precipitation data from Western Regional Climate Center.

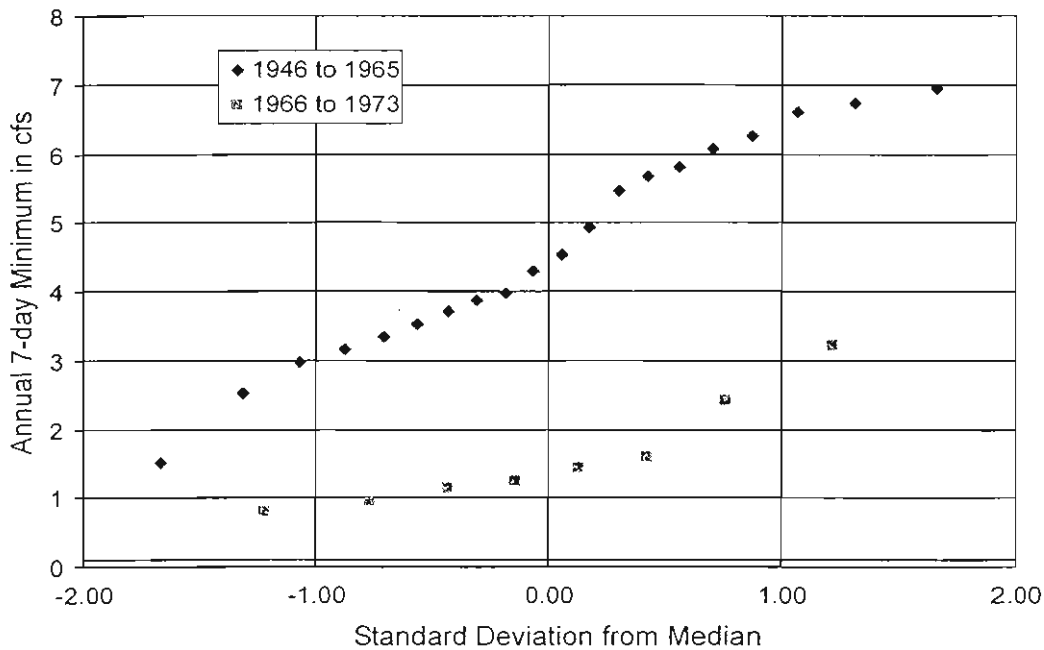
747006F.cdr DNK 4/23/03

HARTCROWSER
7470-06 4/03
Figure 15

# 7-Day Low-Flow Analysis
## Rock Creek Catchment




a) All Data

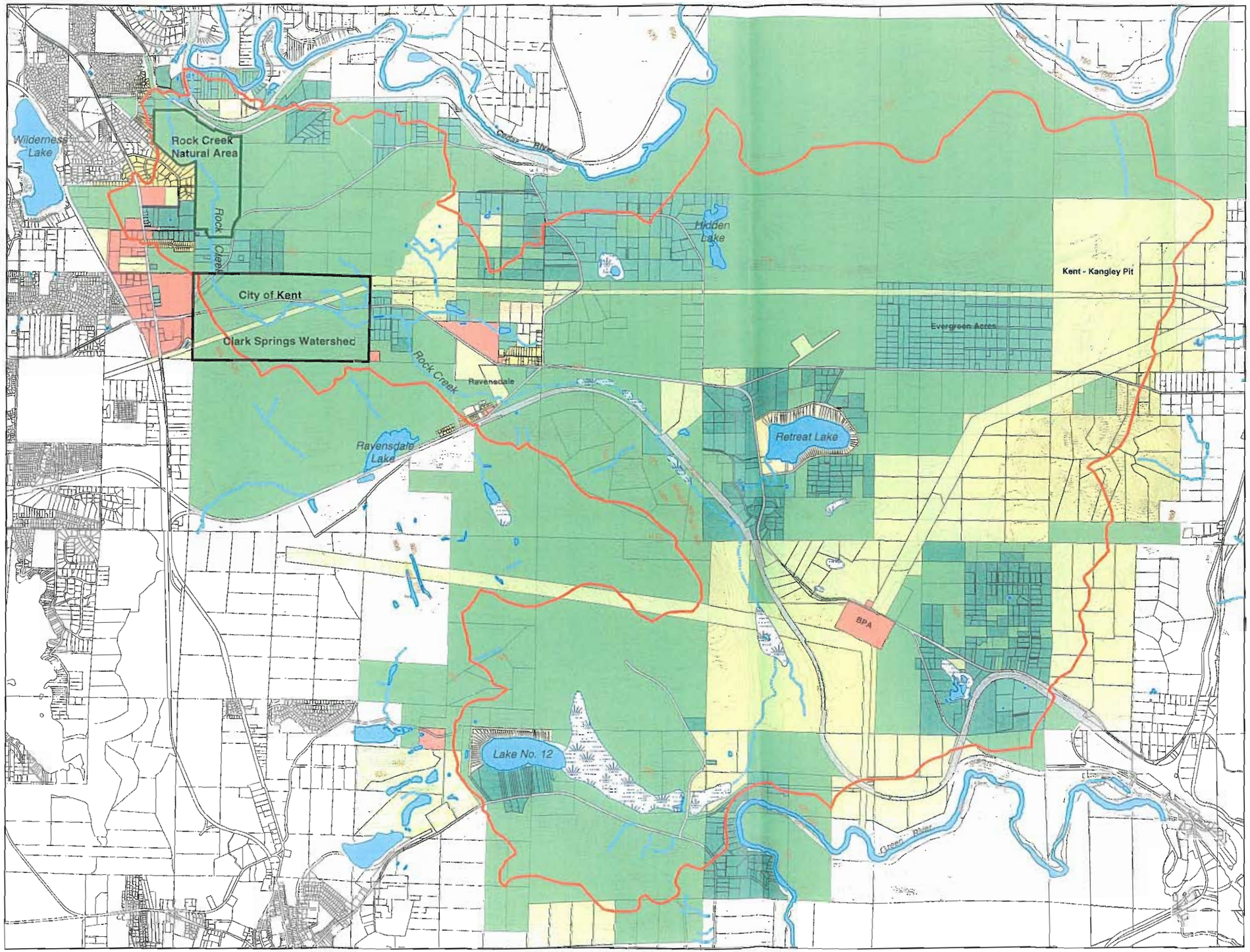



b) Data Split at 1965-1966

747006BJ.CDR DNK 4/23/03

HARTCROWSER
7470-06 4/03
Figure 16

## *1999 Land Use Map*
### *Rock Creek Catchment*




### Legend

- Rock Creek Catchment Boundary
- Rock Creek Natural Area
- Clark Springs Watershed
- Surveyed Stream
- Intermittent Stream
- Surface Water Body
- Wetland (Undelineated)
- Wetland (Delineated by King County)
- 700 Elevation Contour in Feet
- Parcel Boundary

### Land Use Categories

- Forest
- Mixed Forest/Grass
- Grass
- Rural Residential Forest
- Rural Residential Grass
- High Density Residential
- Medium Density Residential
- Commercial/Industrial
- Road/Railroad/Trail
- Wetland

Notes:

1) Parcel coverage based on King County GIS database dated March 2000 provided by City of Kent.

2) Base map data provided by Triathalon at scale 1:24,000 dated April 2001.

N

0 1000 2000 4000 6000

Units in Feet
Scale = 1:36000

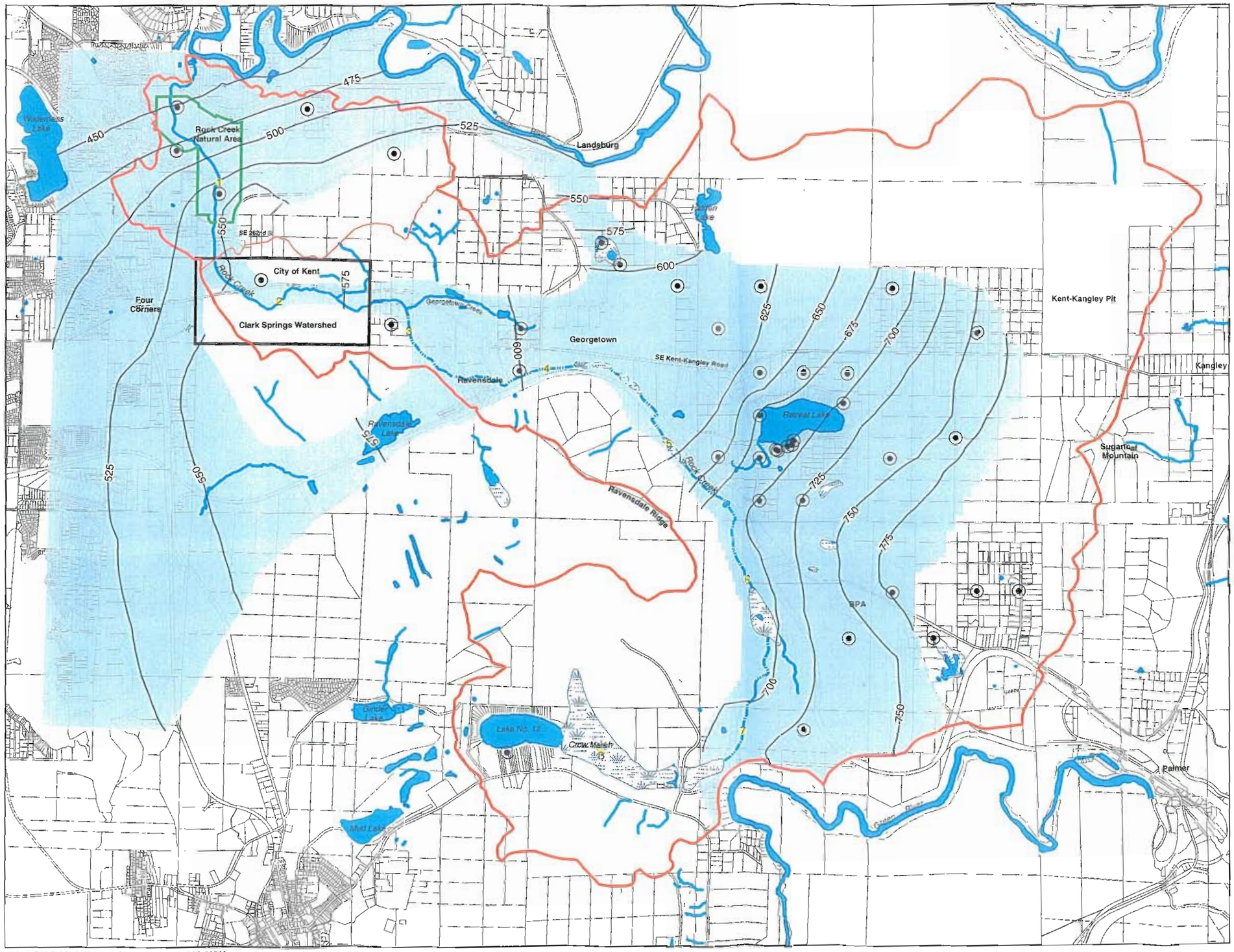
HARTCROWSER

*7470-06* *4/03*

*Figure 17*

c:\jobs\7470\747006\747006-005 (1999 LU Map).mxd COG 4/26/03

# Hydrogeology Map
## Rock Creek Catchment




## Legend

- Rock Creek Mile Marker
- Rock Creek Catchment Boundary
- Boundary between Upper and Lower Basin
- Clark Springs Watershed
- Rock Creek Natural Area
- Surveyed Stream
- Intermittent Stream
- Wetland (Undelineated)
- Wetland (Delineated by King County)
- Surface Water Body
- Parcel Boundary
- Modeled Aquifer Extent (See Appendix F)
- 725 Water Table Elevation Contour in Feet
- DOH Well System Approximate Location

Notes:

1) Parcel coverage based on King County GIS database dated March 2000 provided by City of Kent.

2) Base map data provided by Triathalon at scale 1:24,000 dated April 2001.

3) Drinking Water Well database obtained from the Washington State Department of Health

N

0 1000 2000 4000 6000

Units in Feet
Scale = 1:36000

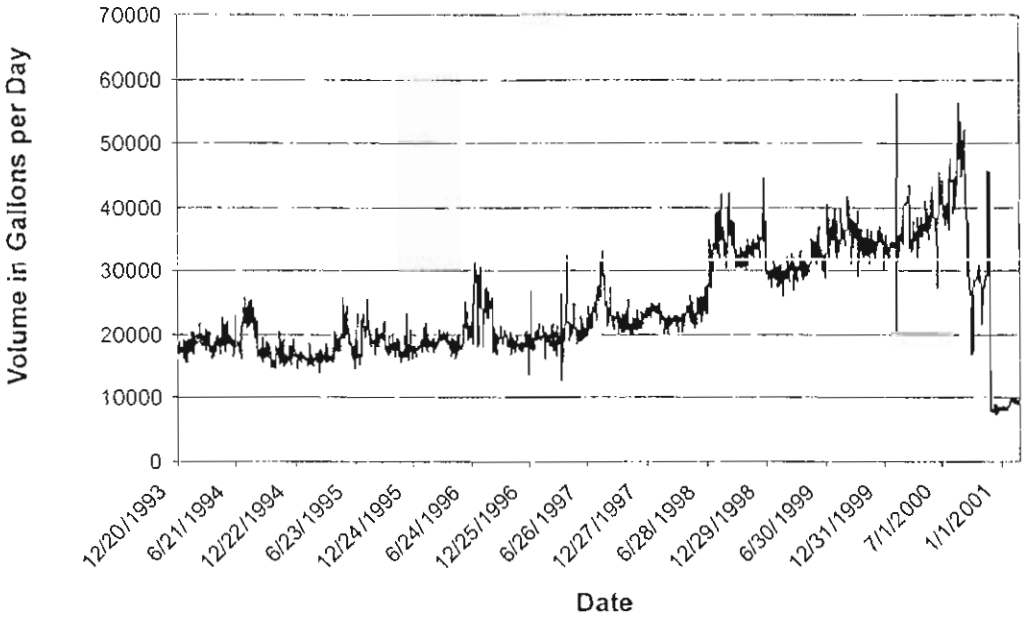
HARTCROWSER

7470-06 4/03

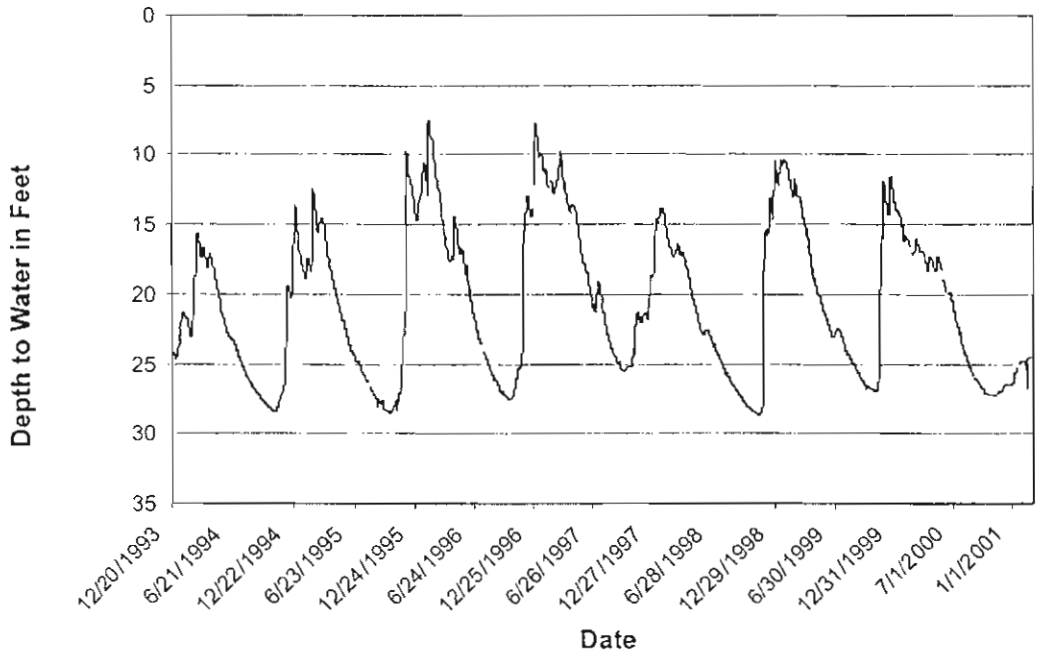
Figure 18

c:\jobs\7470\747006\747006-004 (Hydrogeology Map).mxd COG 4\26\03

# *Ravensdale Well Hydrograph and Volume Pumped*




a) Volume Pumped from Ravensdale Well




b) Hydrograph for Ravensdale Well (3-Day Average)

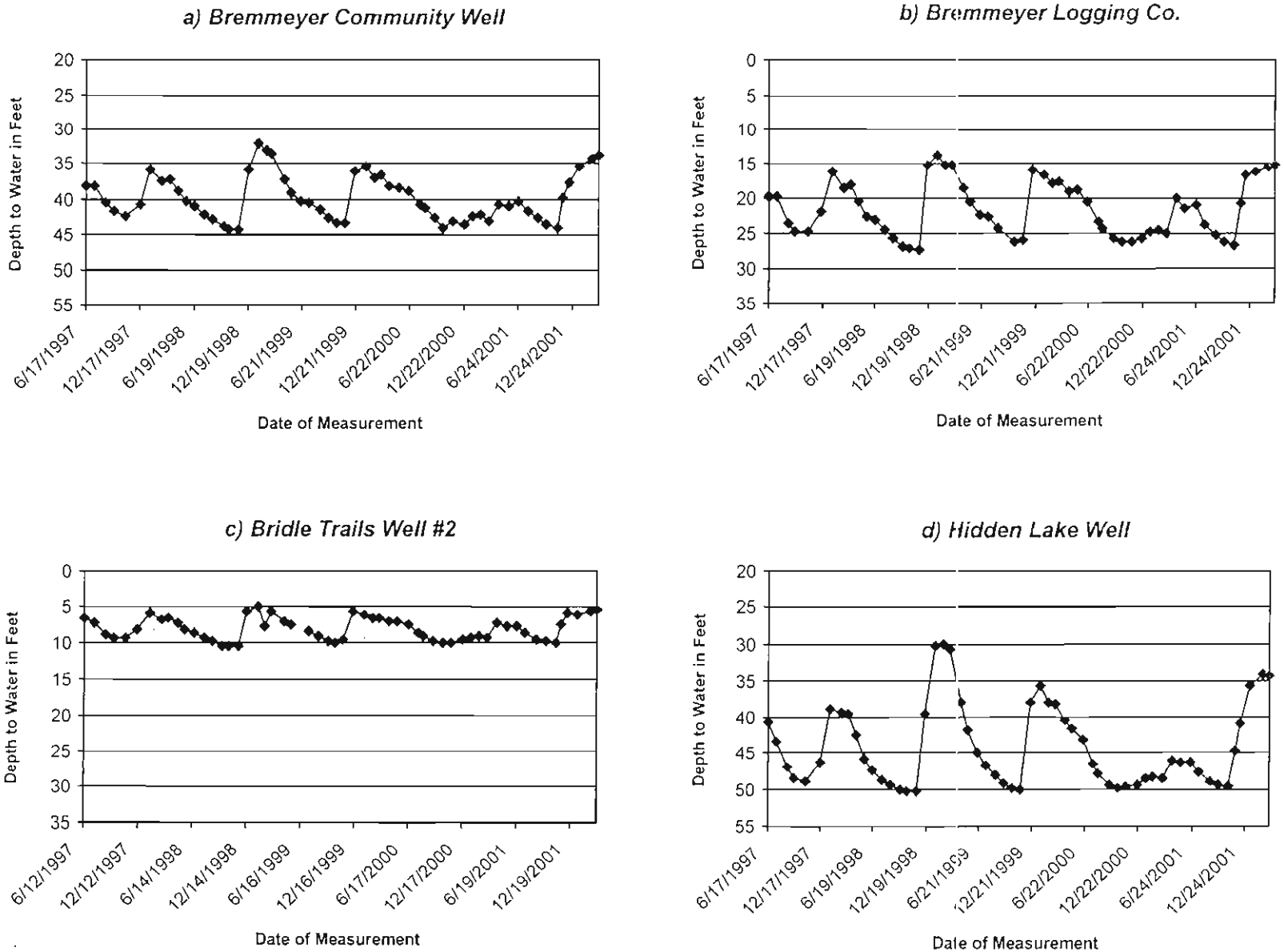
747006G.cdr DNK 4/23/03

HARTCROWSER

*7470-06* *4/03*

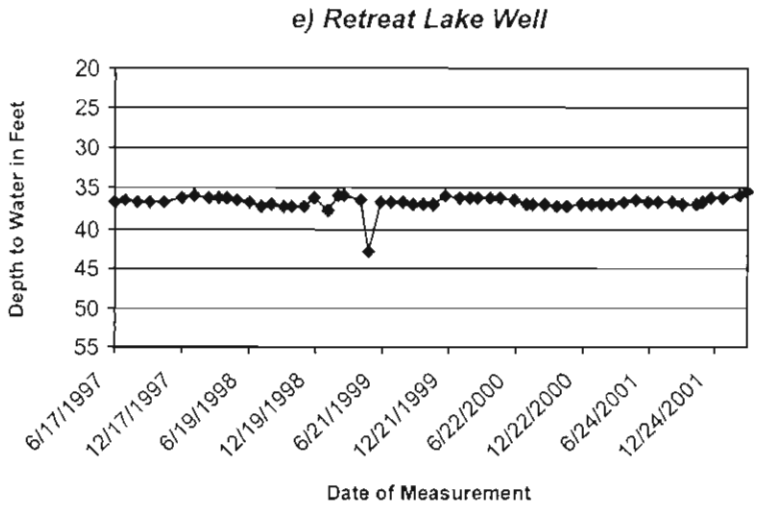
*Figure 19*

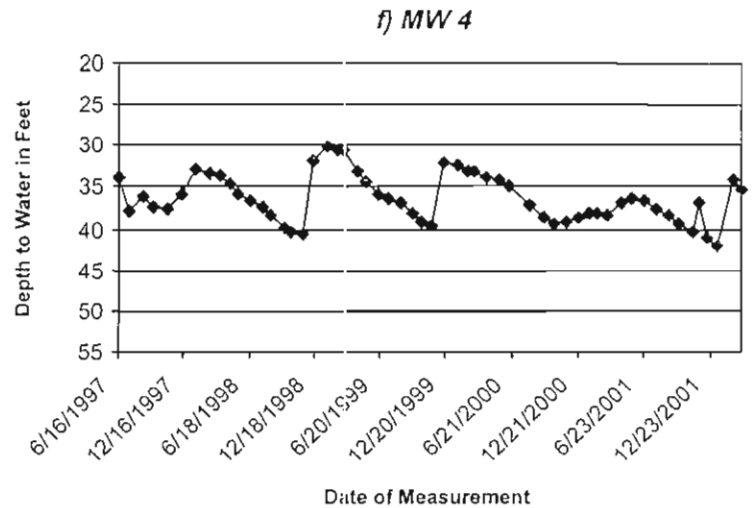
# Hydrographs of Monitoring Wells
## City of Kent Wellhead Protection Area

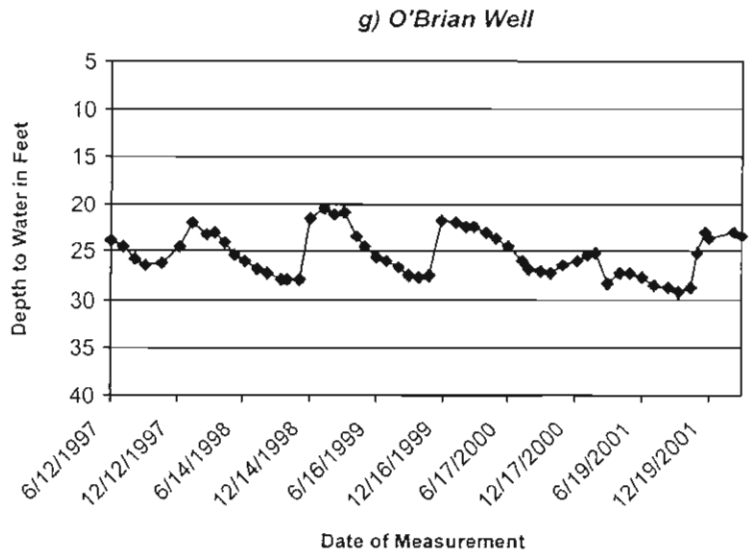


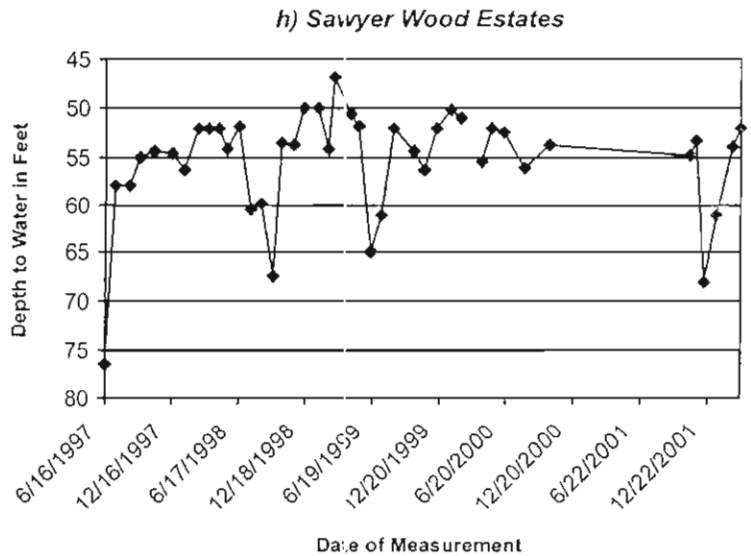

HARTCROWSER
7470-06 4/03
Figure 20 1/2

# Hydrographs of Monitoring Wells
## City of Kent Wellhead Protection Area



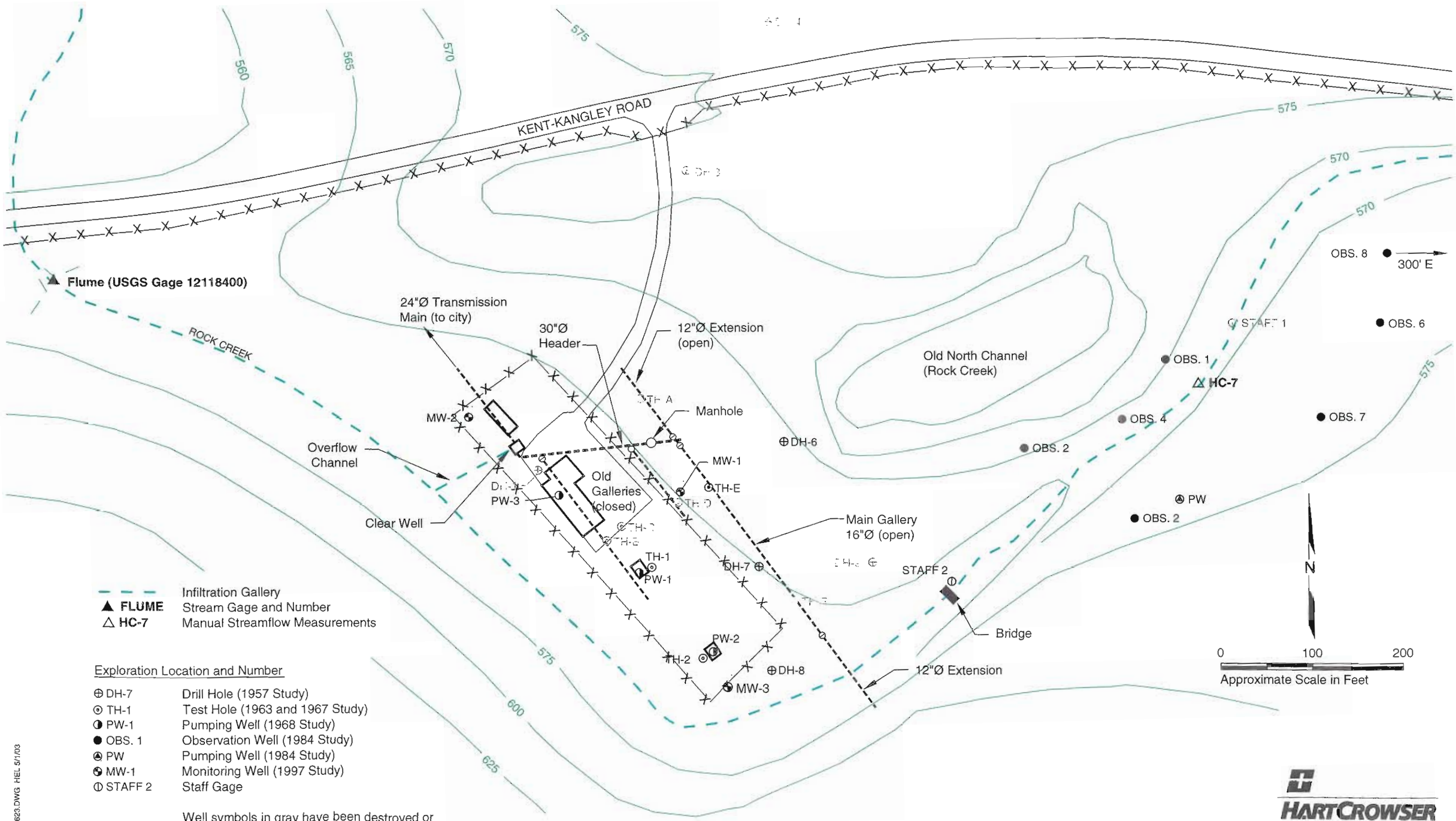




HARTCROWSER
7470-06 4/03
Figure 20 2/2

*This page intentionally left blank.*

## *Site and Facility Map*
### *Clark Springs*




HARTCROWSER

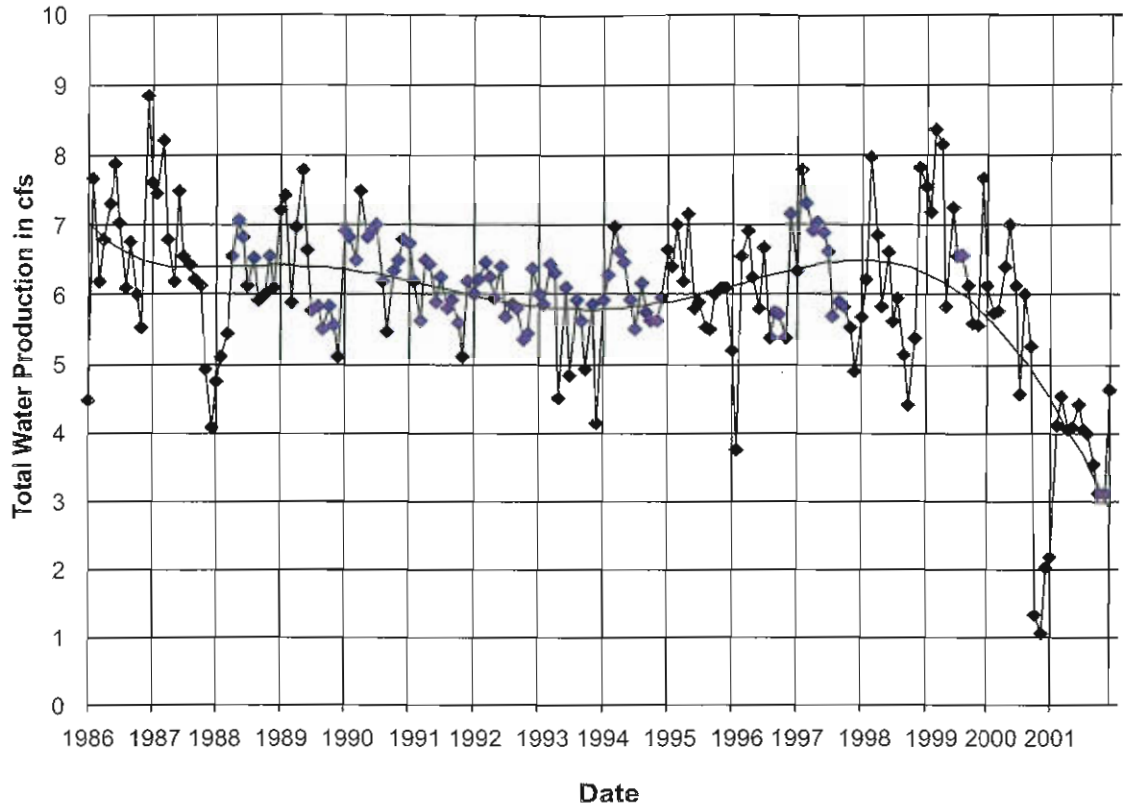
*7470-06* *4/03*

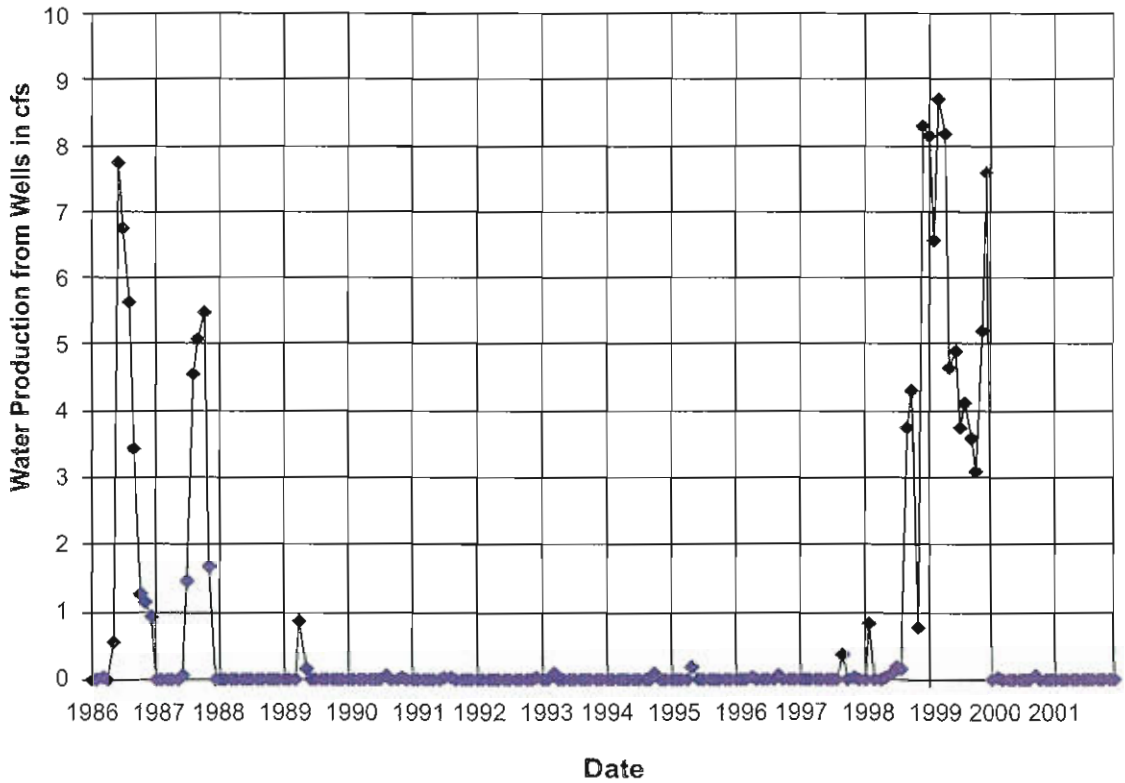
*Figure 01*

7470062B.DWG HEL 5/1/03

*This page intentionally left blank.*

## *Water Production from Clark Springs*



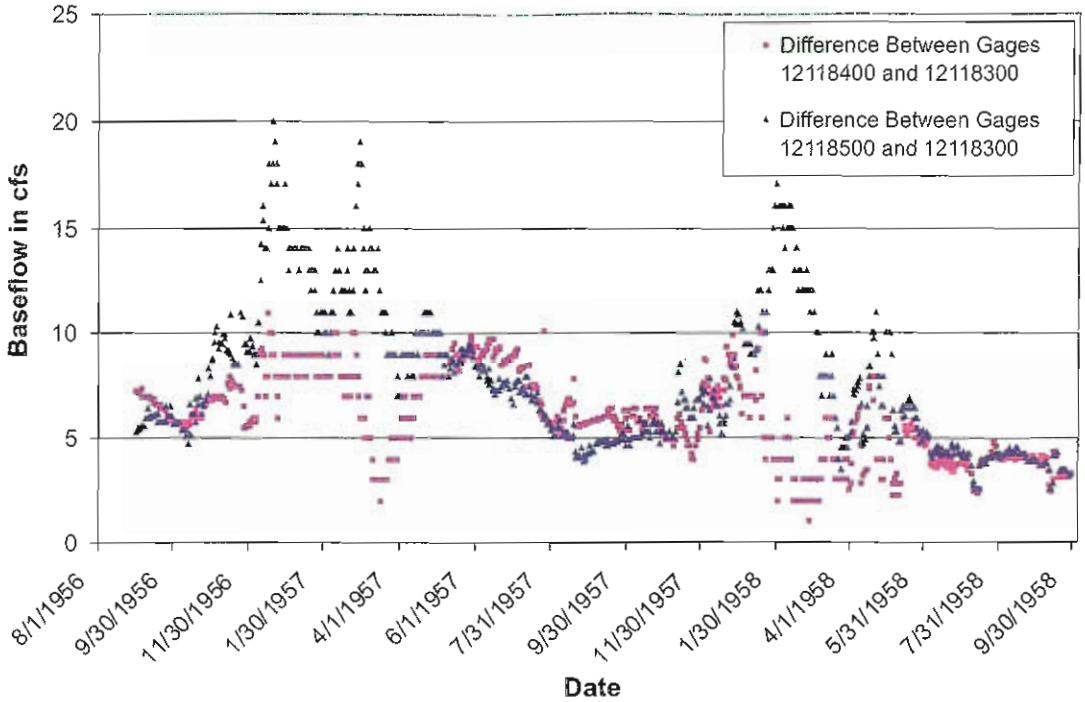

7470066K.CDR HEL 5/1/03

HARTCROWSER

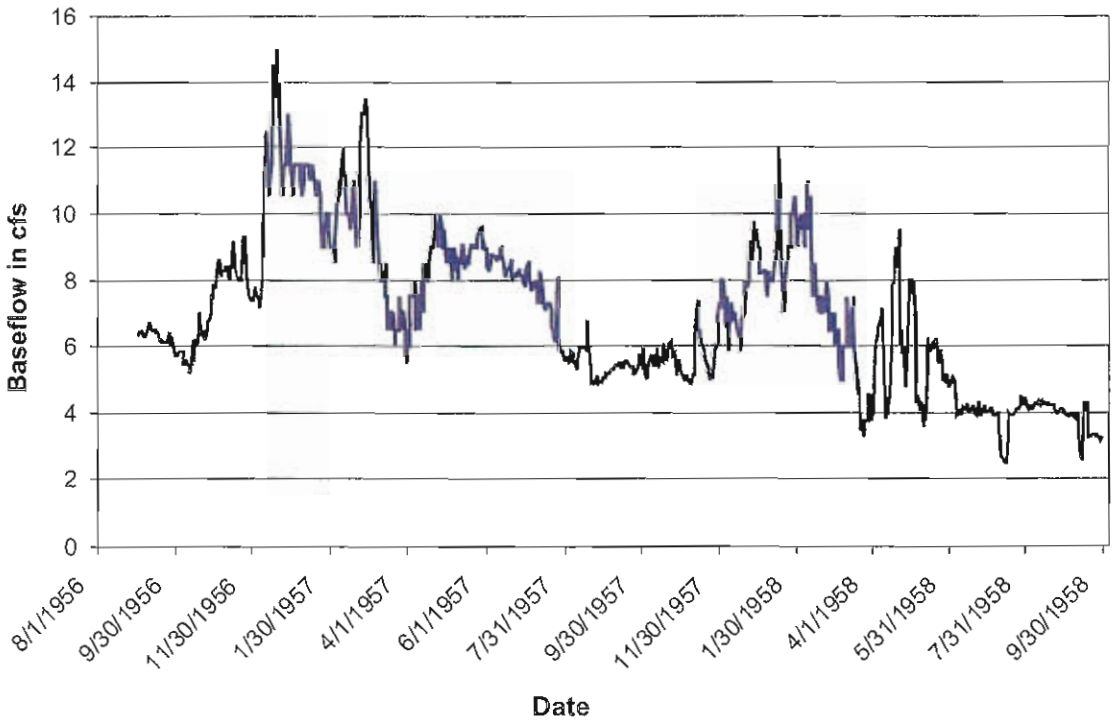
*7470-06* *4/03*

*Figure 22*

# *Interpreted Baseflow of Lower Rock Creek*




a) Interpreted Baseflow of Rock Creek




b) Average Interpreted Baseflow of Rock Creek

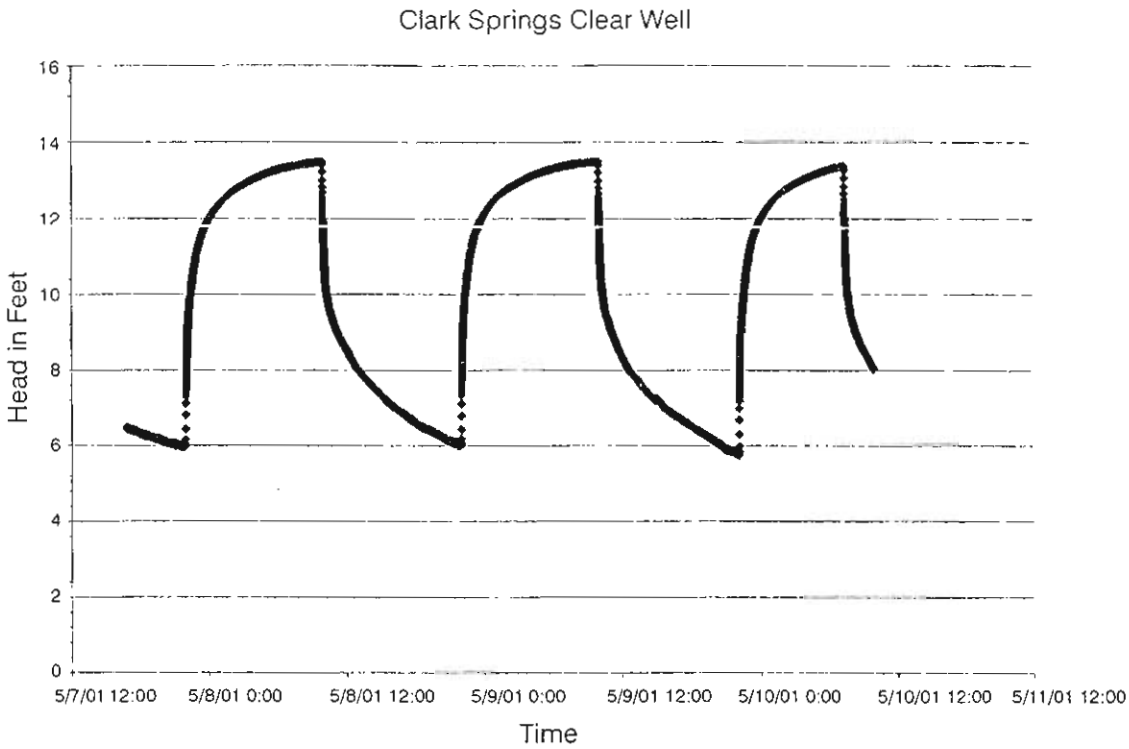
747006H.cdr DNK 4/23/03

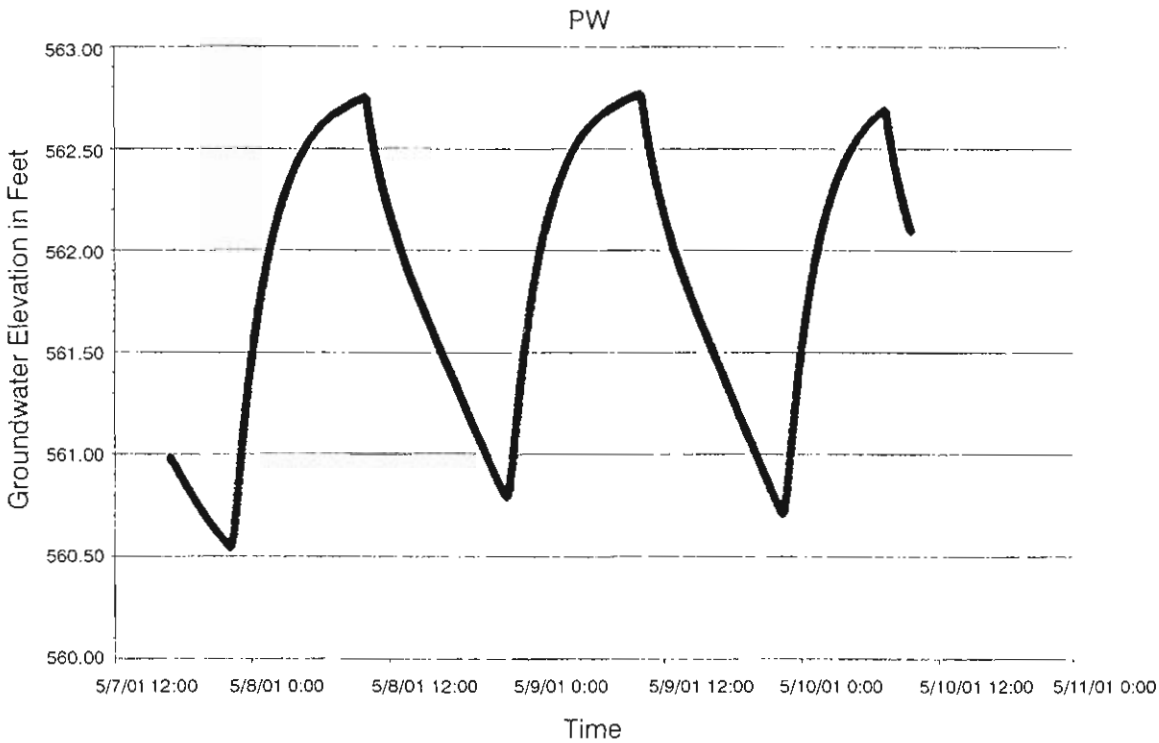
HARTCROWSER

*7470-06* *4/03*

*Figure 23*

# *Clark Springs Infiltration Gallery Test*
## *Rock Creek Catchment*



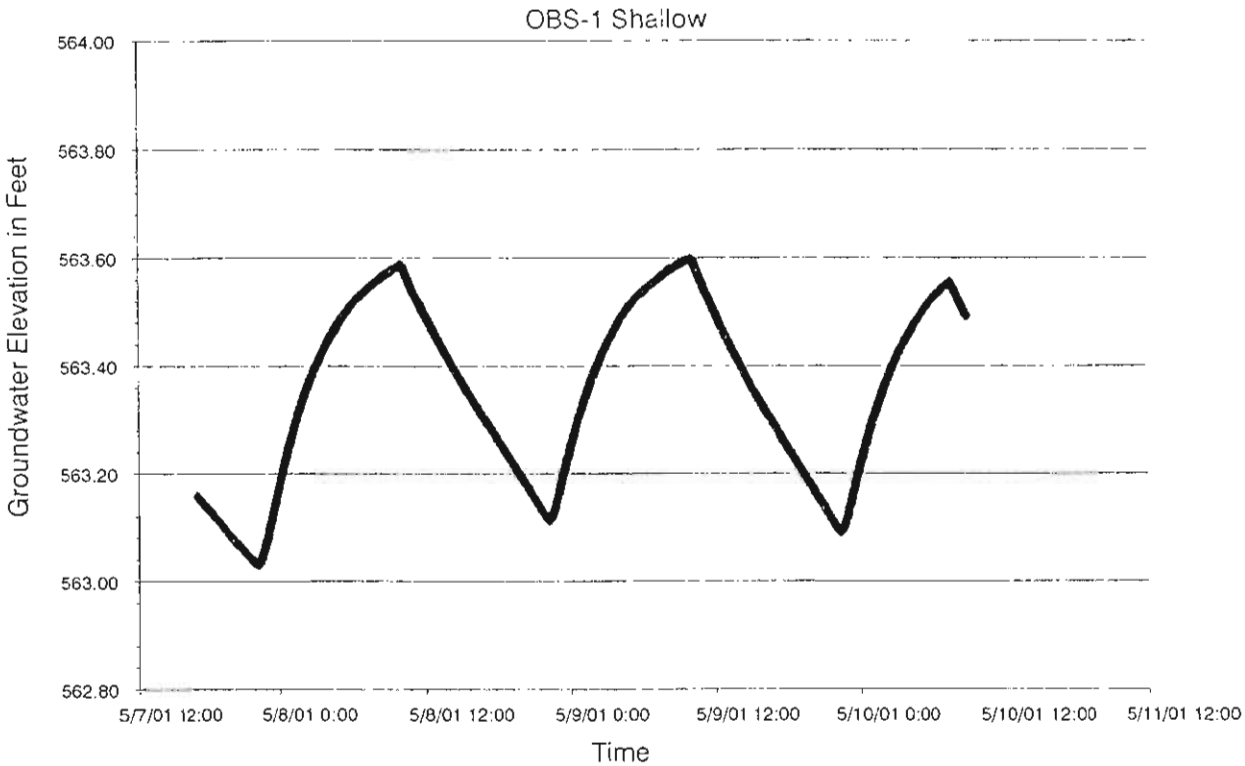

747006B8.CDR DNK 4/23/03

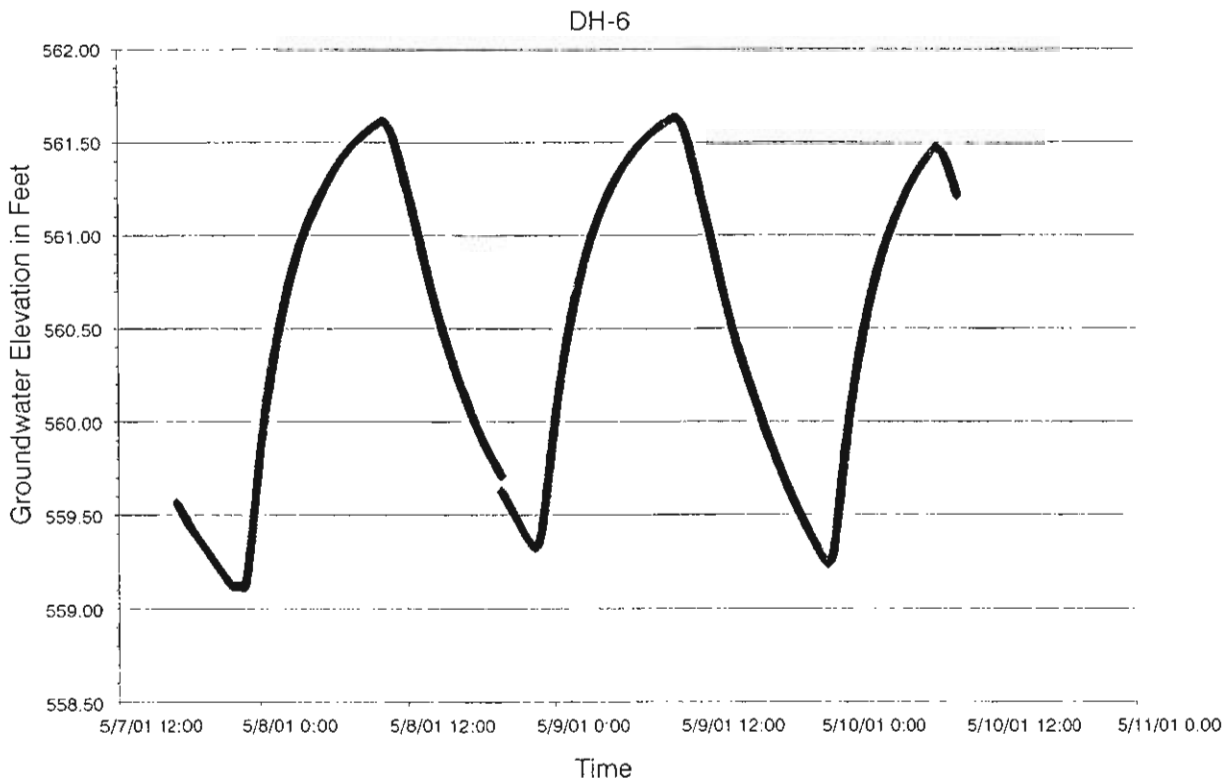
HARTCROWSER

*7470-06* *4/03*

*Figure 24* *1 of 5*

# *Clark Springs Infiltration Gallery Test*
## *Rock Creek Catchment*



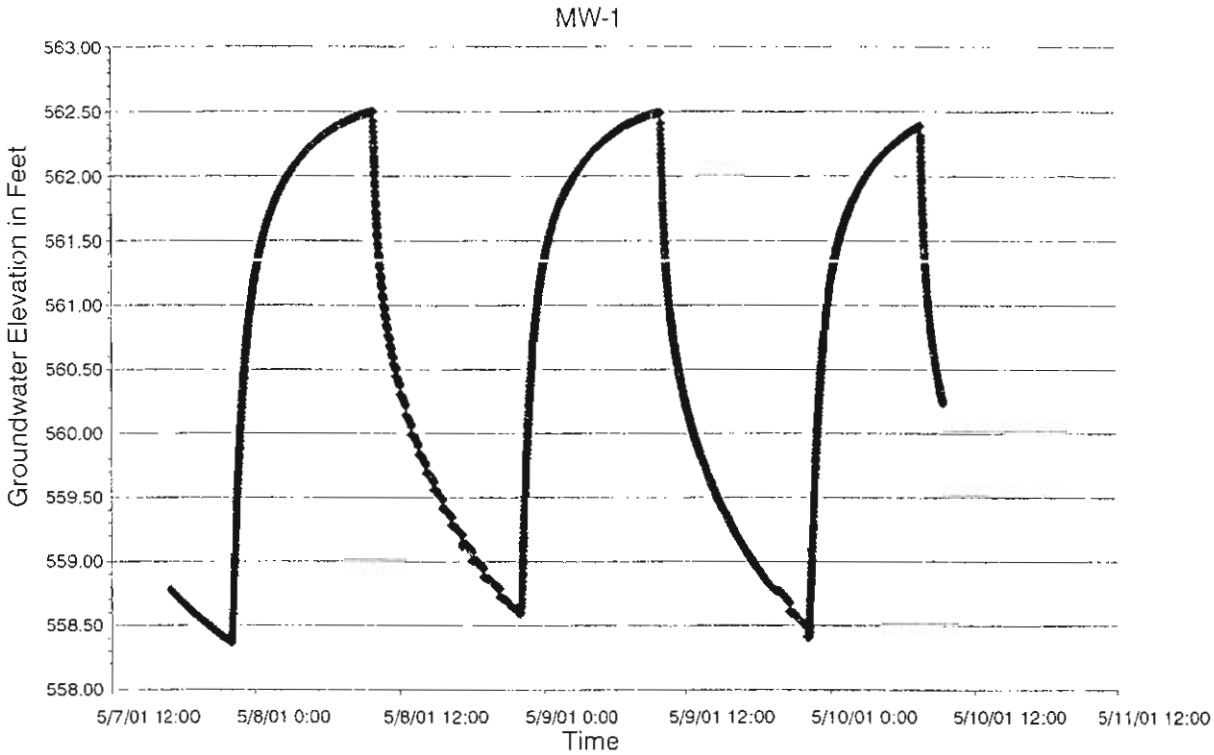

747006BC.CDR DNK 4/23/03

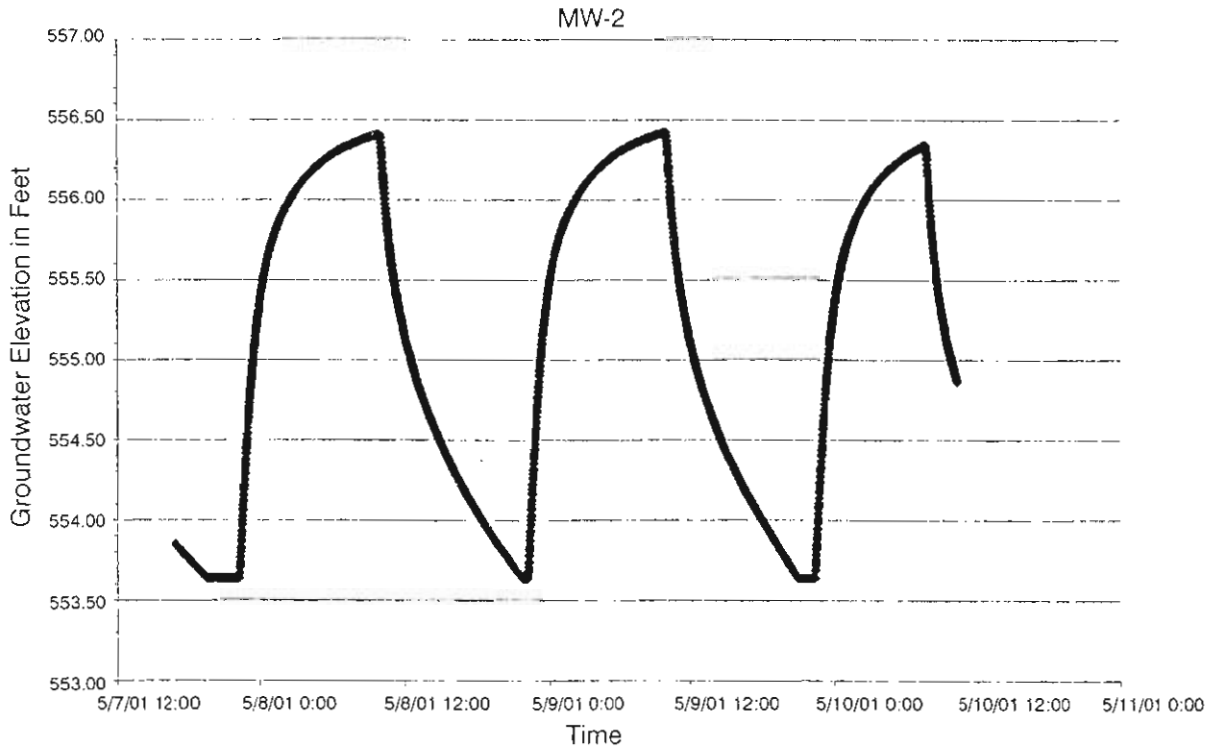
HARTCROWSER

*7470-06* *4/03*

*Figure 24* *2 of 5*

# *Clark Springs Infiltration Gallery Test*
## *Rock Creek Catchment*



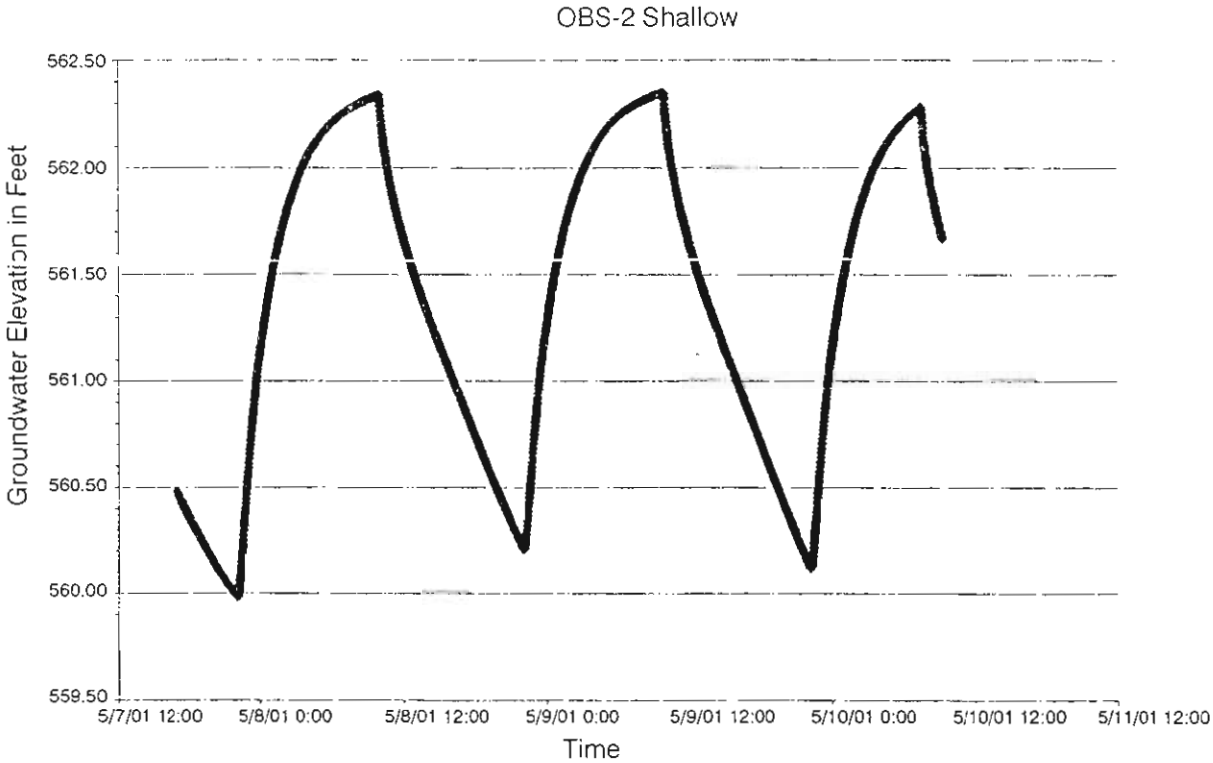

747006BD.CDR DNK 4/23/03

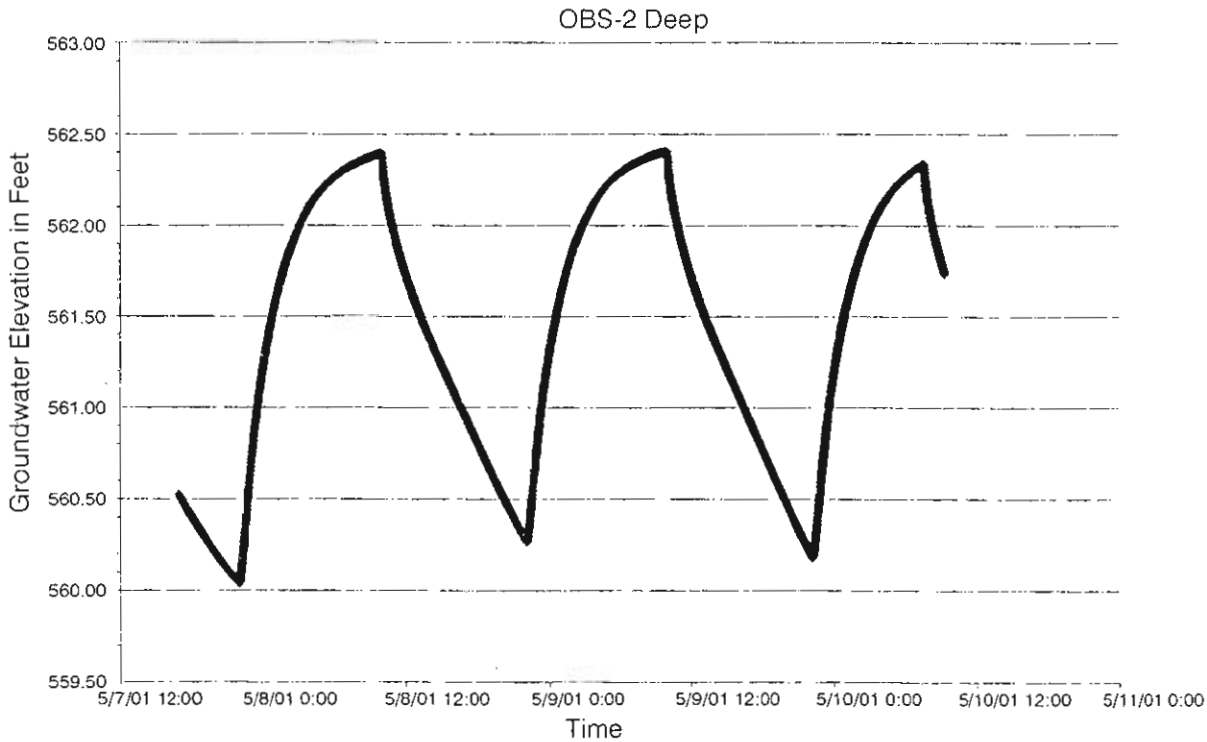
HARTCROWSER

*7470-06* *4/03*

*Figure 24* *3 of 5*

# *Clark Springs Infiltration Gallery Test*
## *Rock Creek Catchment*



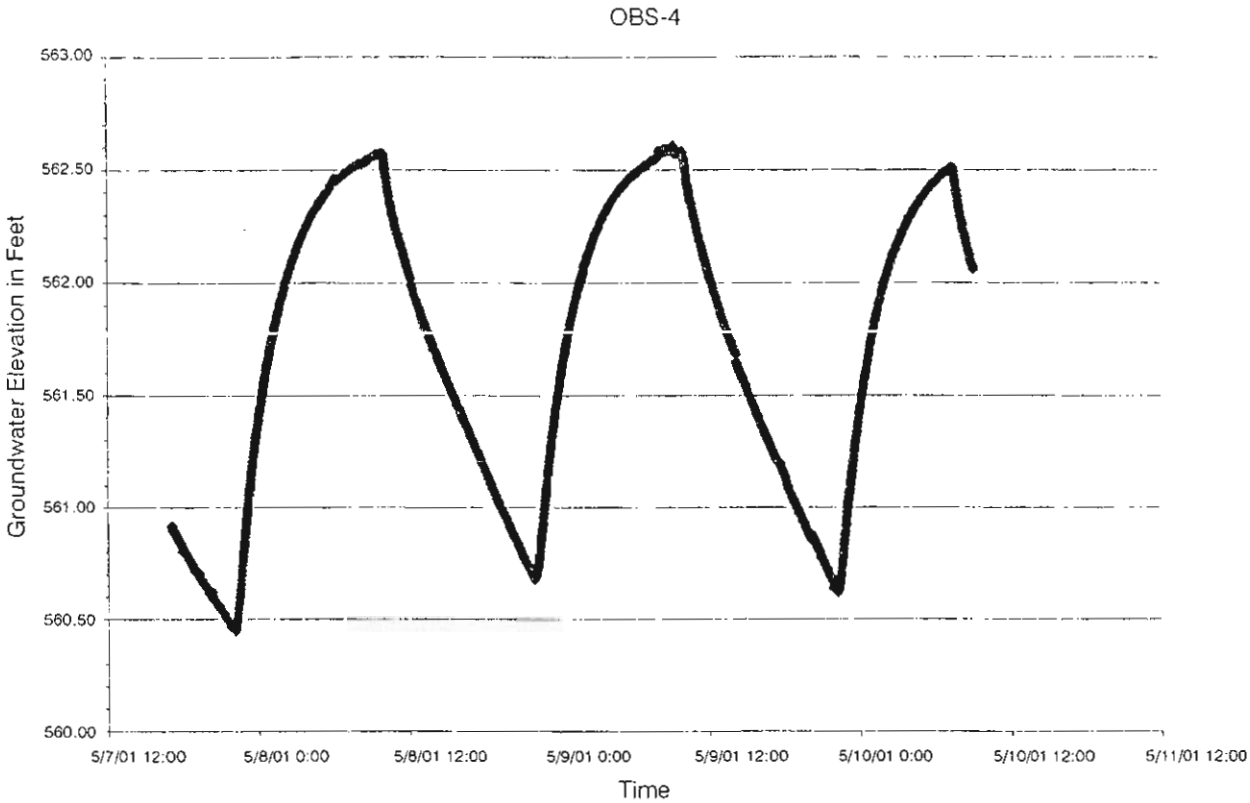



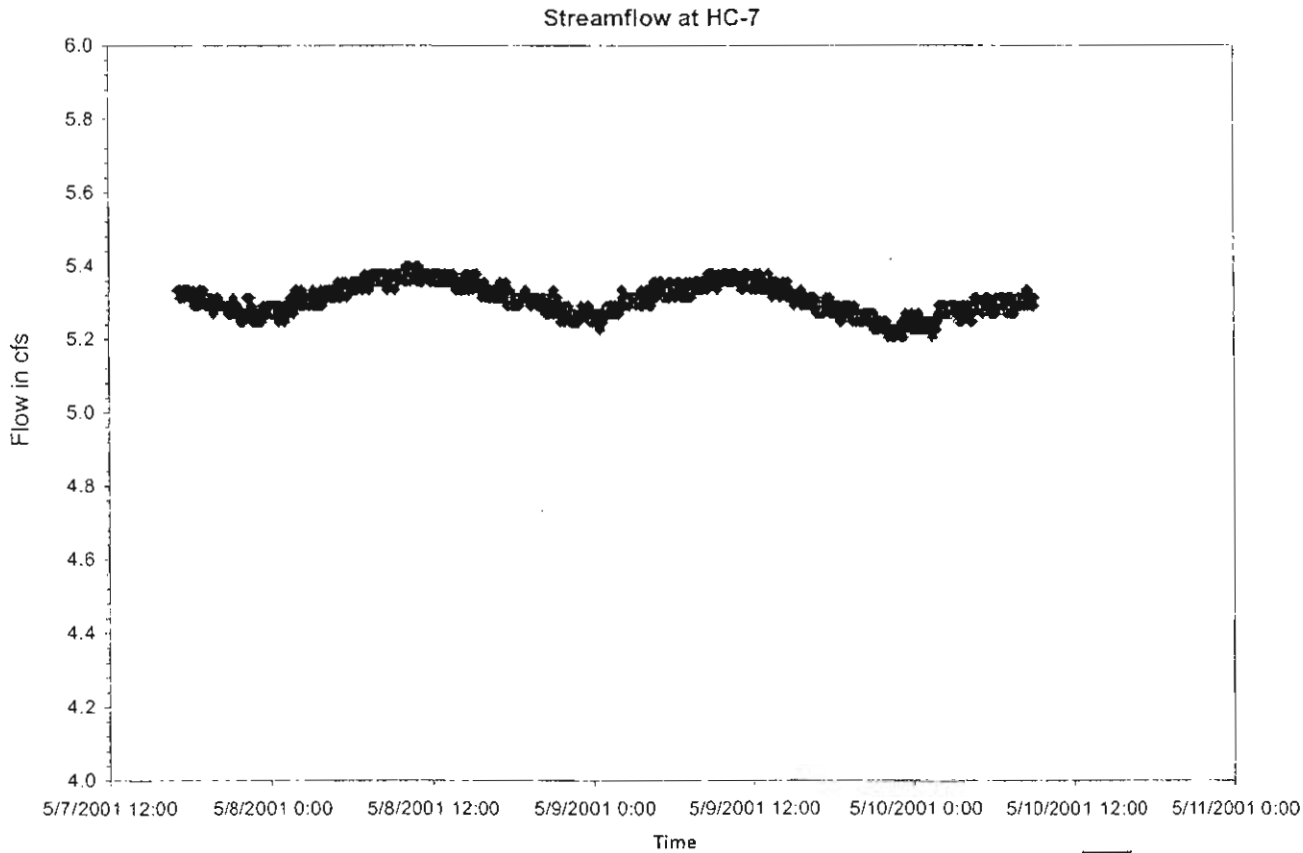

7470068E.CDR DNK 4/23/03

HARTCROWSER

*7470-06* *4/03*
*Figure 24* *4 of 5*

# *Clark Springs Infiltration Gallery Test*
## *Rock Creek Catchment*



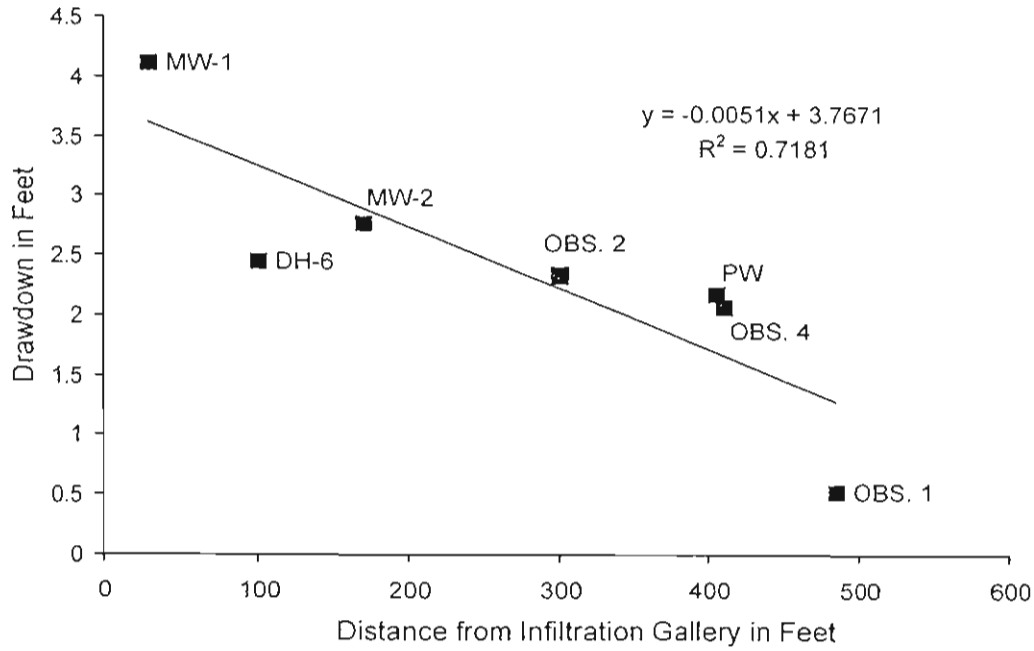

747006BF.CDR DNK 4/23/03

HARTCROWSER

*7470-06* *4/03*

*Figure 24* *5 of 5*

## *Distance-Drawdown Relationship*
*Clark Springs Infiltration Gallery Test*

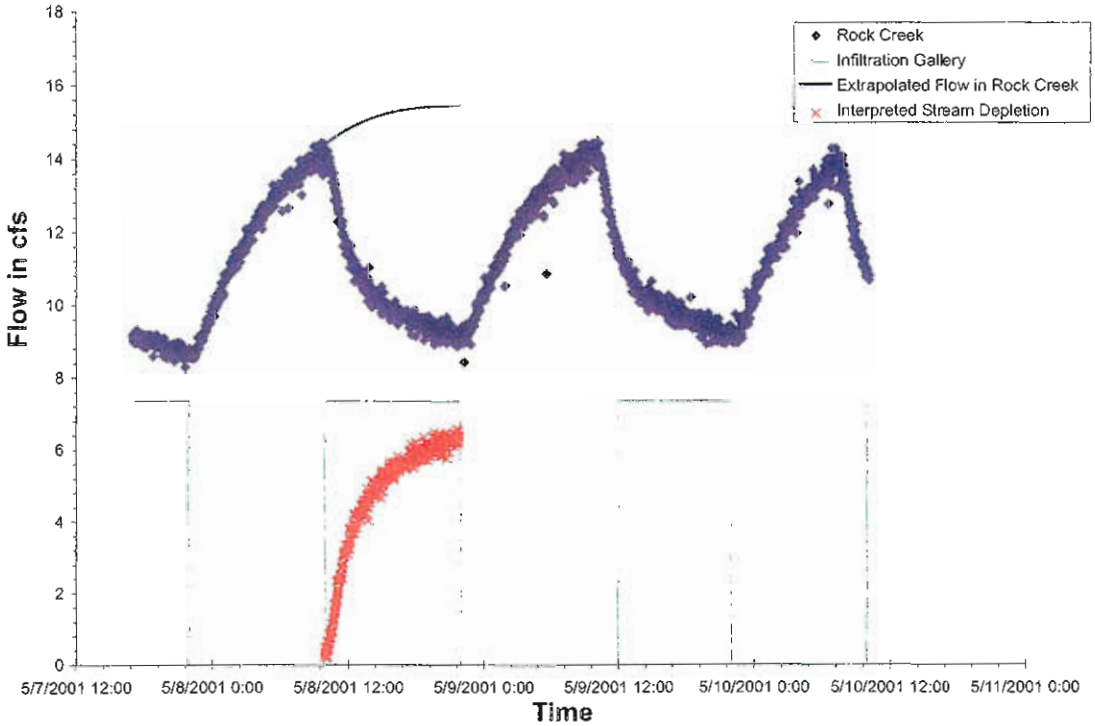



747006BI.CDR DNK 4/23/03

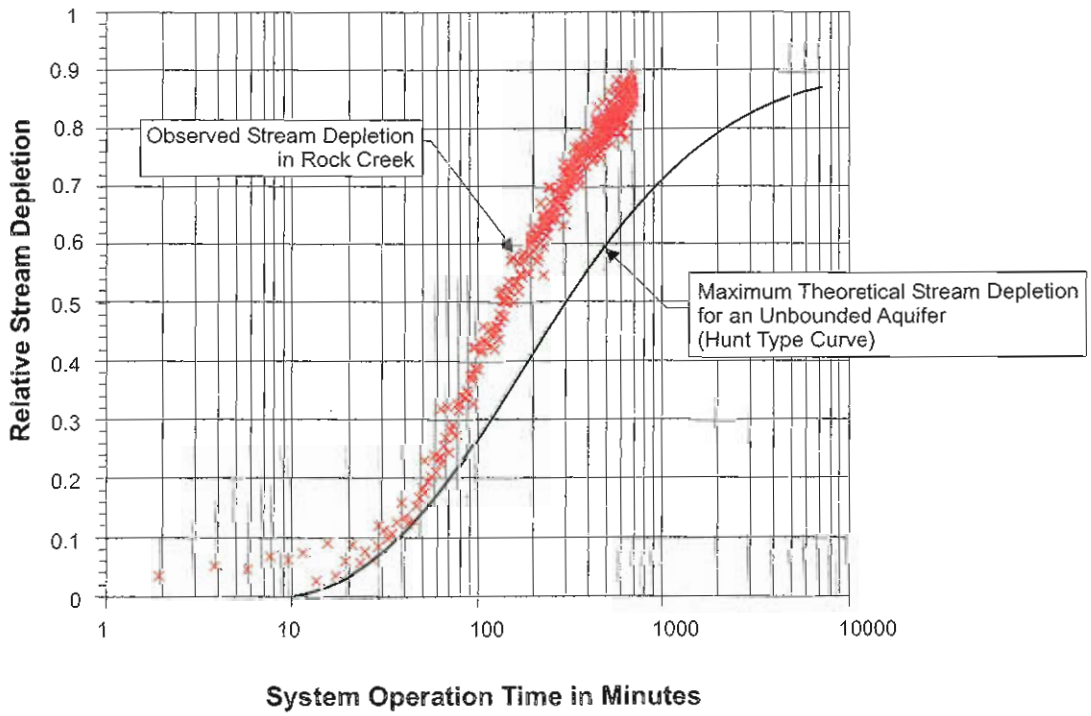
HARTCROWSER
7470-06 4/03
Figure 25

# *Infiltration Gallery System Test*

A)




B)



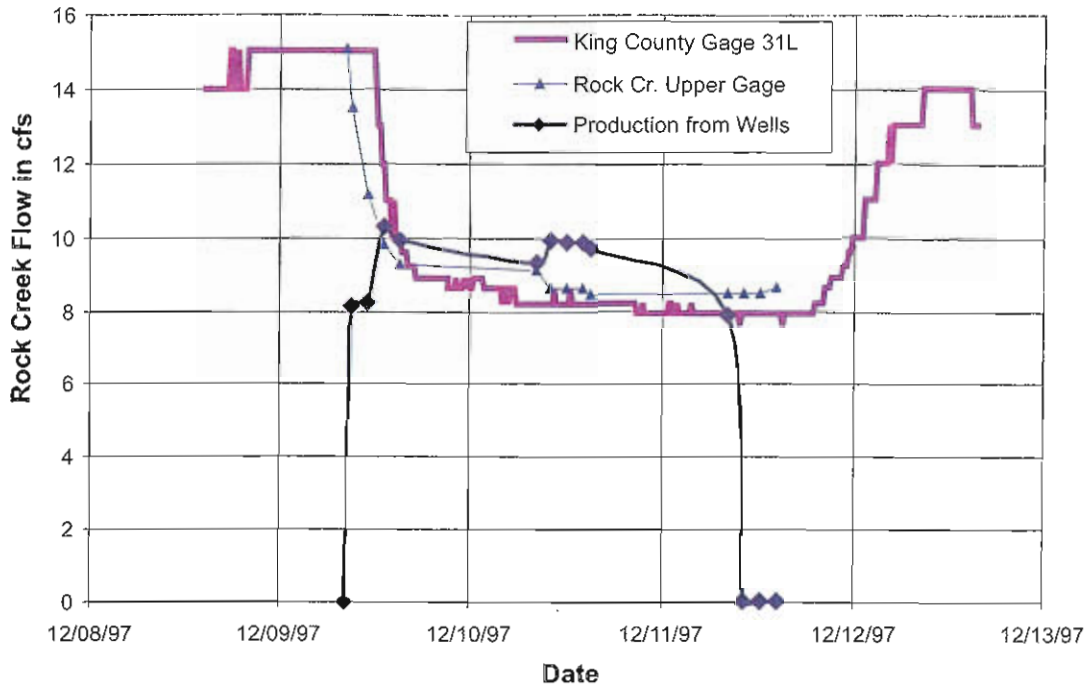

747006BA.CDR DNK 4/23/03

HARTCROWSER

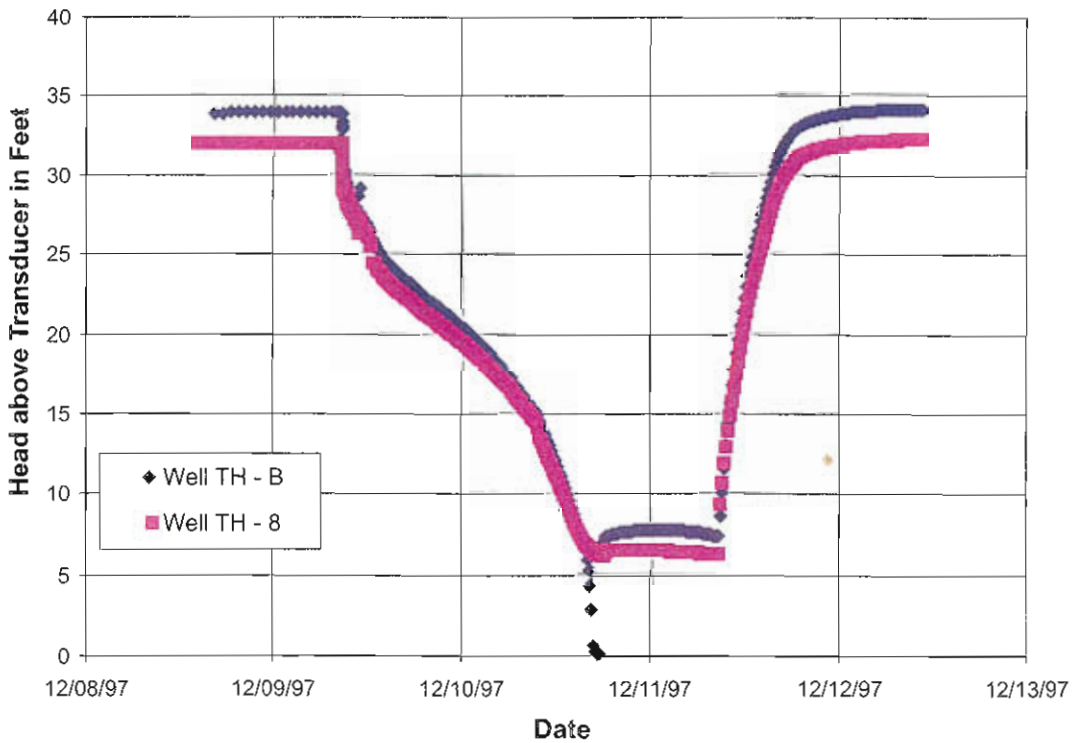
*7470-06* *4/03*

*Figure 26*

## *Clark Springs Wells*
### *Pumping Test-December 1997*




a) Flow in Rock Creek




b) Groundwater Levels from Wells TH-B and TH-8

747006BH.CDR CAS 5/31/02

HARTCROWSER

*7470-06* *4/03*

*Figure 27*

# APPENDIX D

## Rock Creek Basin Groundwater Flow Model

*This page intentionally left blank.*

# Appendix D

## Rock Creek Catchment Groundwater Flow Model

**March 13, 2003**

**The City of Kent was working to complete a Biological Assessment (BA) for its Clarks Springs Operations and this study was to be an Appendix to the BA. However after consideration, the City decided not to conduct a BA but instead to proceed directly with drafting the Habitat Conservation Plan.**

# *Rock Creek Catchment Groundwater Flow Model*

*Prepared for*
*City of Kent Public Works*
*as part of the*
*Clark Springs Biological Assessment*

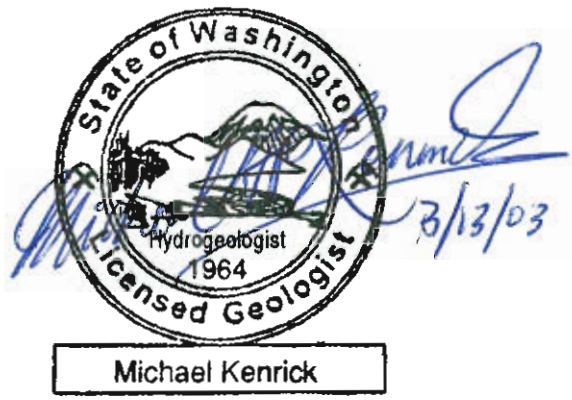
*March 13, 2003*
*7470-05*

***Rock Creek Catchment***
***Groundwater Flow Model***

***Prepared for***
***City of Kent Public Works***
***as part of the***
***Clark Springs Biological Assessment***

***March 13, 2003***
***7470-05***


Prepared by
**Hart Crowser, Inc.**




**Michael A.P. Kenrick, LHG**
Principal Hydrogeologist

## CONTENTS


| | Page |
|---|---|
| **1.0 INTRODUCTION** | 1 |
| ***1.1 Groundwater Modeling Objectives*** | 2 |
| ***1.2 Previous Studies*** | 3 |
| ***1.3 Modeling Approach*** | 3 |
| **2.0 CONCEPTUAL MODEL** | 4 |
| ***2.1 Aquifer System*** | 5 |
| ***2.2 Aquifer and Hydrologic Boundaries*** | 8 |
| ***2.3 Hydraulic Properties*** | 10 |
| ***2.4 Sources and Sinks*** | 11 |
| **3.0 COMPUTER CODE DESCRIPTION** | 14 |
| ***3.1 Assumptions*** | 14 |
| ***3.2 Computer Code Limitations*** | 15 |
| ***3.3 ModFlow Modeling Packages*** | 17 |
| ***3.4 Settings and Model Convergence Parameters*** | 20 |
| **4.0 MODEL CONSTRUCTION** | 21 |
| ***4.1 Model Domain*** | 21 |
| ***4.2 Hydraulic Parameters*** | 22 |
| ***4.3 Sources and Sinks*** | 23 |
| ***4.4 Boundary Conditions*** | 24 |
| ***4.5 Water Balance*** | 25 |
| **5.0 CALIBRATION** | 26 |
| ***5.1 Selection of Calibration Targets and Goals*** | 26 |
| ***5.2 Steady-State Solution*** | 27 |
| ***5.3 Transient Solution*** | 30 |
| ***5.4 Model Application Verification*** | 32 |
| **6.0 PREDICTIVE SIMULATIONS** | 34 |

## CONTENTS (Continued)

Page

**7.0 MODEL LIMITATIONS** 34

***7.1 Model Uncertainty*** 34
***7.2 Additional Studies*** 37

**8.0 SUMMARY AND CONCLUSIONS** 41

**9.0 REFERENCES** 42

## TABLES

1 User Defined ModFlow Solution Parameters
2 Long-Term Groundwater Recharge Values Derived from HSPF for the 1944 to 1998 Period of Record
3 Water Balance for Steady-State Simulation
4 Water Balance and Groundwater Flow Distribution for Transient Simulation

## FIGURES

1 Groundwater Modeling Approach
2 Conceptual Schematic for HSPF and ModFlow Modeling Tasks
3 Modeled Aquifer Extent and Recharge Sub-Basins
4 Bedrock Barrier between Sub-Basins R3D and R3E
5 Modeling Stream-Aquifer Interaction with the Drain Package
6 Model Grid and Boundary Conditions
7 Hydraulic Conductivity Distribution
8 Robinson and Noble Generalized Water Table Elevation Contour Map
9 Simulated Steady-State Water Table Elevation Contour Map
10 Typical Model Cross Section showing Aquifer Thickness
11 Transient Water Level Calibration for the 1998 Water Year, Bridle Trails Well
12 Transient Water Level Calibration for the 1998 Water Year, Bremmeyer Logging Well
13 Transient Water Level Calibration for the 1998 Water Year, Bremmeyer Community Well
14 Sensitivity Analysis: Hydraulic Conductivity Effects on Rock Creek Baseflow
15 Sensitivity Analysis: Specific Yield Effects on Rock Creek Baseflow
16 Sensitivity Analysis: Hydraulic Conductivity Effects on Groundwater Levels – Bridle Trails Well

17 Sensitivity Analysis: Specific Yield Effects on Groundwater Levels - Bridle Trails Well
18 Simulated and Measured Water Levels for the May 2001 System Test

# ROCK CREEK CATCHMENT GROUNDWATER FLOW MODEL

## 1.0 INTRODUCTION

Clark Springs represents the perennial source for streamflow in the lower reaches of Rock Creek, which discharges to the Cedar River and provides potential fish spawning and rearing habitat. The hydrology of Rock Creek is known to be highly influenced by the discharge of groundwater, with baseflow forming a substantial portion of streamflow in the creek, especially during the summer months. The City of Kent's Clark Springs water supply facility relies heavily on the extraction of groundwater, primarily through an infiltration gallery and secondarily through three wells, which draw from the highly transmissive glacial outwash aquifer. In an effort to gain a better understanding of the mechanism of groundwater extraction from the Clark Springs Watershed as well as the hydrologic pathways associated with this groundwater, the City has commissioned a hydrologic modeling study of the Rock Creek catchment.

As an overview, hydrologic modeling of the Rock Creek catchment in support of the Clark Springs Biological Assessment (BA) consisted of a two-tier approach that combined the modeling capabilities of the Hydrological Simulation Program Fortran (HSPF) and the Modular Groundwater Flow code (ModFlow). This approach provides more detailed characterization of the hydrologic flowpaths associated with surface water and groundwater occurring in the Rock Creek catchment.

**HSPF** is designed to simulate continuous surface water flows from a catchment, based on precipitation inputs, land use, soil types, and a host of other hydrologic parameters. It divides the catchment into sub-basins in which the various hydrologic properties are lumped together and analyzed for their overall effect on the resulting streamflow. It represents all parts of the hydrologic cycle, including groundwater, using spatially aggregated response functions that are not always physically based. Accordingly, its representation of groundwater flow is simplistic and highly idealized, but HSPF is nevertheless widely recognized and accepted locally as the tool of choice for simulating the overall hydrology of a catchment in terms of the streamflow produced at a given point in the system.

**ModFlow** is strictly a groundwater flow model that simulates the movement of subsurface water in an aquifer, although it can simulate the exchange of water that occurs between an aquifer and a surface water body. ModFlow solves the

complex differential equations for groundwater flow throughout the model domain, taking account of spatial variations in properties such as recharge, aquifer thickness, and hydraulic conductivity. The results that ModFlow generates include the water table elevation, spatially distributed throughout the model, together with inflows and outflows in spatial positions that correspond directly to their real locations.

Documentation of the HSPF and ModFlow modeling efforts has been separated into different appendices to the Clark Springs BA (Appendix C and F, respectively) thereby providing a thorough analysis of each hydrologic process. The remainder of this report specifically addresses modeling efforts associated with the shallow groundwater system within the Rock Creek catchment.

## *1.1 Groundwater Modeling Objectives*

The scope of this work was to create and calibrate a sub-regional groundwater flow model encompassing the upper and lower catchments of Rock Creek, and including adjoining areas surrounding the Clark Springs Watershed. The primary objectives of the groundwater modeling efforts were to:

- Gain a better understanding of the dynamic nature of the groundwater basin hydrology including; flowpaths, distribution of groundwater to the flowpaths, and recharge time-lag/storage properties of the aquifer;

- Incorporate into the model representation of the complex linkage between the surface water and groundwater within and downstream of the Clark Springs Watershed;

- Evaluate the effects of past, present, and future land use practices within the catchment on the local surface water/groundwater system; and

- Understand the effects of water supply withdrawals at Clark Springs on flows both upstream and downstream in Rock Creek.

The work was performed in concert with other ongoing technical studies on Rock Creek, especially the HSPF modeling performed by MGS (Appendix C of the BA), and the Hydrogeology Study performed by Hart Crowser (Appendix E of the BA). The main focus of the modeling work was initially to understand stream-aquifer interactions in the lower portion of Rock Creek that could be affecting flow in the perennial reaches of the stream. However, as the work

progressed, field data and streamflow analysis indicated that groundwater interactions with the lower reaches were minimal due in the main to the unique geologic setting of the Rock Creek. Furthermore, the importance of the water resource created in the upper catchment became more apparent in terms of its control on the overall availability of water as groundwater discharge at Clark Springs during critical periods of low flow.

## 1.2 Previous Studies

Previous groundwater modeling studies that included all or part of the Rock Creek catchment are summarized below:

- GeoEngineers (2000) prepared a ModFlow groundwater model for the evaluation of seasonal high water table during various storm events as part of a boundary line adjustment for the McCann property, upstream of Clark Springs. Their model focused on the area northeast of Ravensdale Lake where the normally dry Rock Creek stream channel turns and heads northwest toward the Clark Springs Watershed.

- Hart Crowser (1996) developed a regional groundwater model using ModFlow for assessing wellhead protection capture zones via steady-state simulations. The eastern extent of the model encompassed the area modeled for this work scope but the western boundary extended to Armstrong Springs. The north-south extents of that model were similar to our current model extents.

The overall size of the models, discretization of space, and modeling objectives associated with the previous studies do not allow for a direct comparison to the current modeling efforts; however, their conceptual models and input data provided a basis for establishing a more detailed and robust groundwater model specifically for the Rock Creek catchment in support of the Clark Springs BA.

## 1.3 Modeling Approach

The chosen modeling approach was to simulate the generalized groundwater flow patterns within the shallow aquifer that occupies the Rock Creek catchment using a computer-based single-layer finite difference modeling package called ModFlow (short for Modular Groundwater Flow code), the most widely used and broadly accepted industry-standard tool for this purpose.

The general approach for the modeling efforts related to this work scope was to build upon and refine previous modeling efforts performed within the Rock Creek catchment. Our approach involves modeling the catchment area that contributes flow to Clark Springs; therefore, we have not physically expanded the domain covered by the previous models but rather incorporated conceptual ideas. The chosen modeling approach expands modeling capabilities beyond previous investigators by:

- Incorporating well-defined groundwater recharge input data as a result of detailed precipitation analysis in the HSPF modeling;
- Providing steady-state solutions for the entire basin thereby enabling analysis of specific flow path regimes and associated quantities; and
- Introducing transient analysis of highly variable and time-dependent recharge input data for evaluating the response time of the upper catchment and the buffering effect of groundwater storage on recharge events, and on the overall response of the downstream flow system.

Modeling efforts and documentation of these efforts as related to this work scope have encompassed or paralleled industry-standard procedures. Beyond the site-specific elements of the modeling approach discussed above, our overall approach has followed the flow chart developed by Anderson and Woessner (1992), depicted on Figure 1.

## 2.0 CONCEPTUAL MODEL

Conceptual model development is an integral part of the groundwater modeling process in which the overall geometry, structure, and physical properties of the groundwater system are characterized and described. The conceptual model of the groundwater flow system provides the basis for the construction, calibration, and overall use of the computer-based groundwater model.

We have sub-divided our conceptual model of the Rock Creek catchment into specific sections (listed below) as they relate to model construction and calibration, based on our understanding of the hydrology and hydrogeology of the basin as depicted schematically on Figure 2. Additional detail on specific topics such as geologic units and groundwater/surface water interaction are presented in Appendix E of the BA.

## *2.1 Aquifer System*

The aquifer system comprises the physical aspects of the modeled aquifer such as depth, aquifer type, and flowpaths. Conceptual understanding of the aquifer system contributes directly to the level of detail (size and number of layers) that the model will exhibit. The aquifer system of the Rock Creek catchment is characterized by a shallow unconfined aquifer that occurs in surficial glacial deposits underlain by bedrock at typical depths of between 60 and 150 feet. The bedrock is relatively low in permeability and is assumed to form an impermeable base to the shallow aquifer system. The aquifer is divided areally into three sections:

- The upper catchment;
- Intermediate *aquifer channels* in which the outwash aquifer is laterally confined between bedrock hills at points where the groundwater leaves the upper catchment; and
- The downgradient aquifer, which receives discharging groundwater from the intermediate aquifer channels.

The Clark Springs Facility, where the City extracts groundwater, is located within one of the three intermediate aquifer channels occurring in the Rock Creek catchment (see Figure 2).

### 2.1.1 Upper Catchment

The upper portion of the Rock Creek catchment occupies a relatively flat plain surrounded by a ring of bedrock hills that are partially capped by glacial till. The direct infiltration of precipitation into the relatively permeable glacial outwash deposits occupying the plain serves as the primary source for groundwater recharge and water supply in the Rock Creek catchment. Precipitation in the small bedrock sub-basin (R8) that holds Lake No. 12 is also an important source of flow in the upper reaches of the Rock Creek stream channel. Discharge from this sub-basin enters the upper part of the creek, either as surface flow or as shallow groundwater flow that recharges the aquifer (see Figure 2).

In geographic terms, it is perhaps surprising that the uppermost sub-basin (R8) of the Rock Creek system does not discharge directly to the Green River at this point, given their remarkable proximity. Indeed, earlier work (Brown & Caldwell

1978 and 1980) considers this sub-basin and most of the upper Rock Creek catchment as part of the Green River system, and not the Cedar River system. This incorrect distinction is still reflected in the current delineations for Water Resource Inventory Areas (WIRAs) 8 and 9 (Ecology 2003), with almost the entire upper catchment of Rock Creek shown to be within the Duwamish/Green WIRA.

It is concluded for modeling purposes that the potential for natural groundwater flow from the area east of Lake No. 12 to the Green River must be limited by the relatively high elevation of the bedrock lip forming the northwestern wall of the Green River canyon at its closest approach to the Rock Creek stream channel. However, some seeps and flows have been reported by the park ranger at the Green River State Park. Some loss of water from the Rock Creek catchment to the Green River cannot be ruled out but one assumption underlying the modeling work is that this represents at most a relatively small amount of the total catchment recharge.

Based upon our review of the literature and available data on the geology in the area, the shallow outwash aquifer in the upper Rock Creek catchment is dominated by the occurrence of highly transmissive outwash channels (as described in Appendix E of the Clark Springs BA). These reflect the later stages of glacial deposition and reworking by glacial meltwater as the Puget Sound lobe receded from the area (see Appendix E), depositing substantial thicknesses of very coarse granular material (sand, gravel, cobbles, and boulders) in broad swaths or channels that trend across the Rock Creek upper catchment from northeast to the west and south. The current course of Rock Creek appears to follow one such outwash channel, skirting Ravensdale Ridge in the southwest of the upper catchment. A second major conduit exists in the larger east-west trending outwash channel located in the northern part of the upper catchment. Recharge from the eastern and southern portions of the catchment flows into this major outwash channel and discharges to the west.

### 2.1.2 Intermediate Aquifer Channels

The majority of groundwater discharging from the upper catchment flows westward through the Georgetown/Ravensdale area. Flow in the shallow outwash aquifer becomes funneled into aquifer channels that convey the groundwater between till-capped bedrock hills located to the north (Landsburg Ridge) and south (Ravensdale Ridge). In this area, the aquifer is only a mile wide at its narrowest point. A third till-capped hill (Maple Ridge), located to the west

of Ravensdale, divides the groundwater flow, with a portion flowing southwest down the Ravensdale aquifer channel while the remainder flows directly west along the Rock Creek aquifer channel and into the Clark Springs Watershed (see Figure 2).

A third aquifer channel (the Landsburg aquifer channel), appears to provide an additional pathway for groundwater to exit out of the upper catchment along a northwest trending valley that leads down to the Cedar River at Landsburg. However, the fines content of the sediments and closely spaced water table elevation contours inferred in this area indicate that the volume of flow occurring through this aquifer channel is limited when compared to the two other highly transmissive aquifer channels described above.

The percentage of groundwater entering the Rock Creek and Ravensdale aquifer channels has not been determined or estimated prior to this work scope, but has been calculated from calibrated model results presented in this report (see Sections 5.2.1 and 5.3.1). The division of flow is thus a product of the model development process. This process is based on the following known or estimated characteristics as input to the model:

- Aquifer channel geometry;
- Apparent geology of channel infill;
- Inferred water table and hydraulic gradient; and
- Modeled recharge rates, groundwater flows, and discharges.

The calculated division of flow reflects in part the overall water balance for the Rock Creek catchment as represented in the model, and the amount of flow monitored at the Clark Springs flume and removed by the Clark Springs water supply facility. These last two data streams represent the only available physical measurements of flow components within the hydrologic system against which the model can be compared.

### 2.1.3 Downgradient Aquifer

The glacial outwash aquifer extends west and north beyond the Clark Springs Watershed, and to the southwest beyond Ravensdale. Limits of the lower Rock Creek catchment, as shown on Figure 2, represent the topographic divide, which is very poorly defined in areas downstream of Clark Springs. The outwash aquifer extends under and beyond this area, with groundwater flow crossing the catchment boundary, as shown on Figure 2.

The western portion of the downgradient aquifer receive groundwater discharge from the Rock Creek and Ravensdale aquifer channels with the westward groundwater flow crossing the basin boundary and entering the adjacent Covington Creek drainage. The aquifer deepens with increasing distance to the west, as the bedrock drops away into the Puget Sound trough, and the shallow aquifer becomes underlain by less permeable pre-glacial deposits. Only a portion of the downgradient aquifer outside of the Rock Creek catchment has been included in the model, sufficient to facilitate the simulation of groundwater discharge from the Rock Creek and Ravensdale aquifer channels.

North of Clark Springs, groundwater flows from the Clark Springs area and also from the Landsburg aquifer channel to replenish the small portion of outwash aquifer on the southern flank of the Cedar River valley. Groundwater in this area flows toward and discharges to the Cedar River. This portion of the aquifer between Landsburg and the mouth of Rock Creek has been included in the model domain even though it is outside of the Rock Creek catchment boundary, to provide a relatively realistic groundwater flow connection with the Cedar River.

## 2.2 Aquifer and Hydrologic Boundaries

Boundary conditions are established in ModFlow to regulate inflow and/or outflow from the model. Location of boundary conditions is the primary concern in modeling applications; placement too close to the area of interest may allow the boundary to dominate the solution.

The modeled extent of the outwash aquifer and its associated hydrologic boundaries are presented on Figure 3. The extent of the aquifer east of the Rock Creek and Ravensdale aquifer channels is generally defined by the foot of till-capped bedrock hills that surround the upper catchment. The outwash aquifer does not extend up the flanks of these hills, which are typically steep and underlain by till and low-permeability bedrock. These surface layers contain and release minimal quantities of water to the shallow aquifer, but act as conduits for surface runoff (overland flow) and shallow interflow that contribute to recharge of the adjacent outwash aquifer beneath the floor of the Rock Creek valley plain. Therefore, the flanks of the hills are not represented directly as groundwater flow regimes within the ModFlow model, although the runoff components are calculated in HSPF and added to the recharge from direct precipitation that occurs in the floor areas.

To the west of the aquifer channel outlets, the outwash aquifer extends westward but we have established an artificial downgradient boundary for the Rock Creek model. This boundary extends along a north/south line drawn between Lake Sawyer and Wilderness Lake. A subsection of the downstream aquifer is thus included within the conceptual model even though it falls strictly outside the Rock Creek catchment boundary. This ensures that potential hydraulic effects related to assumptions about the downstream boundary of the model are sufficiently distant that they do not propagate back into the main area of interest for the modeling tasks.

The Cedar River provides a clear hydrologic boundary in the northwest area of the model. This is defined as a constant-head boundary set at the approximate mean elevation of the river, as shown on the USGS 7½-minute quadrangles, which increases from 300 feet at Maple Valley to 510 feet at Landsburg. The model does not take into account elevation changes in the stage of the Cedar River though the seasons. Due to the physical configuration of the model domain, stage changes on the order of 5 to 10 feet in the Cedar River would only affect groundwater levels close to the river and are considered to be inconsequential when compared with the elevation range (300 to 700 feet) for the water table within the model.

Parts of the northern boundary in the upper catchment are less well-defined due to the absence of clearly identifiable till-covered bedrock hills between Hidden Lake and the Kent-Kangley gravel pit. Specifically, the area encompassed by recharge sub-basins R3C, R3E and R3F (Figure 3) are topographically within the Rock Creek catchment, but the fate of precipitation in these areas is not clearly defined.

**Sub-Basin R3C.** Based on the presence of till on higher ground in the area north of the main east-west outwash channel, and the apparent absence of a bedrock core in this upland area, our conceptual model assumes that recharge likely flows to the north, entering the Cedar River directly rather than via the Rock Creek system. However, there are indications that the bedrock barrier described below extends along the southern boundary of this sub-basin. Surface water runoff (modeled in HSPF) from this area is considered to report to Rock Creek.

**Sub-Basin R3E.** King County's water level analysis, prepared for the Kent-Kangley Gravel Pit EIS (King County 1987), shows a substantial difference in groundwater levels between sub-basins R3D and R3E. The presence of volcanic pinnacles, and a mapped northwest trending fault with a western upthrown fault

block, strongly indicate that the portion of the aquifer in sub-basin R3E is not hydraulically connected with the rest of the aquifer in the upper catchment. Figure 45 from King County (1987) is reproduced as Figure 4 of this report to demonstrate the evidence supporting this interpretation. Therefore, we have concluded that groundwater flow discharges northward from sub-basin R3E, directly to the Cedar River, and does not contribute to flow in Rock Creek. This part of the aquifer in the catchment is therefore not simulated in the ModFlow model.

**Sub-Basin R3F.** The fate of precipitation in the area of the Landsburg aquifer channel is also not clearly defined, with this area possibly acting as a closed basin that feeds surface flows to Cranberry Marsh At least part of the recharge in this sub-basin likely flows to the north, entering the Cedar River rather than discharging via Rock Creek.

## *2.3 Hydraulic Properties*

The hydraulic properties associated with the shallow outwash aquifer that are fundamental to the groundwater flow model are *hydraulic conductivity*, a measure of the permeability of the aquifer, and *specific yield*, a measure of the water released from or taken into storage when the water level in the aquifer changes. The aquifer's ability to transmit water is a function of the permeability as well as the thickness of the aquifer; these two properties are traditionally combined to provide a measure of the aquifer *transmissivity*, its ability to transmit groundwater flow.

Although no aquifer testing was performed in this work scope, others have tested the aquifer in various locations to determine specific values for aquifer transmissivity. As part of the well database assembled for a Wellhead Protection Program, Robinson and Noble (1995) reported the range of transmissivity for the outwash aquifer to be 5,400 to 17,000,000 gpd/ft (722 to 2,272,727 $ft^2/d$) with a median value of 73,000 gpd/ft (9,759 $ft^2/d$), based on values calculated at 20 well locations. The range of these values is consistent with values determined for similar outwash deposits in the Puget Sound lowland.

Hydraulic conductivity values can provide a reasonable check during model construction and calibration, i.e., keeping values within documented ranges for specific aquifer materials. For instance, Domenico and Schwartz (1990) have documented gravel hydraulic conductivities to range from 283 to 283,000 ft/d. Back-calculating Robinson and Noble's estimates of transmissivity, using

modeled values for aquifer thickness, calculates hydraulic conductivities that fall within this documented range.

As discussed in more detail in Section 5.2, the initial hydraulic conductivity values were derived from previous investigators; however, the final hydraulic conductivity values selected for the model were those that generated water levels matching the target water levels. It should be noted that the distribution of conductivity values arrived at during the model calibration process (see Section 5.0) represents only one plausible solution of the modeling task. The distribution of hydraulic conductivity can be varied within the ranges quoted, and other changes made in areas where model geometry or hydraulic conditions are not clearly understood, to still yield a calibrated solution. In this sense, the calibrated distribution of hydraulic conductivity is not unique.

The transient model requires the definition of *aquifer storativity* for active model cells. In an unconfined aquifer, the storativity is also called the *specific yield* and represents the portion of aquifer porosity at the water table that drains readily under the force of gravity. For confined aquifers, including lower layers in ModFlow that are always below the water table, the storativity is known as the *storage coefficient*, which takes account of the aquifer or layer thickness and represents the changes in storage due to elastic compression or expansion of the aquifer matrix and its contained water. In ModFlow, this value is further reduced to the *specific storage*, which is independent of aquifer or layer thickness.

## 2.4 Sources and Sinks

Contributions and withdrawals of water to the aquifer system are defined as sources and sinks, respectively. For the Rock Creek catchment, these include precipitation and infiltration; flows to and from lakes, streams, and other surface water bodies; and groundwater withdrawals.

### 2.4.1 Precipitation and Infiltration

The primary recharge source for the Rock Creek catchment groundwater system is the infiltration of precipitation occurring within the upper topographic catchment. The relationship between the extents of the topographic catchment boundary and the shallow outwash aquifer is shown on Figure 3. With the exclusion of water from sub-basin R3E, the portion of precipitation occurring in each sub-basins that becomes groundwater recharge is considered to produce and sustain groundwater flow in the shallow outwash aquifer.

Although a significant proportion of direct precipitation infiltrates the highly permeable aquifer soils, some precipitation is lost via evapotranspiration. Additional recharge to the aquifer occurs as runoff and/or interflow from the flanks of the till-capped bedrock hills that form the elevated parts of the topographically defined catchment. These hydrologic processes have been simulated for the Rock Creek catchment as part of the HSPF modeling task (see Appendix C of the BA); values of net recharge calculated for each sub-basin using HSPF have been applied over the representative areas of the ModFlow model. Further explanation of the recharge distribution adopted for the groundwater model is provided in Section 4.3.1.

### 2.4.2 Lakes and Surface Water Bodies

Lakes and other surface water bodies represent locations of water sources or sinks within the basin, depending on their inferred relationship with the shallow outwash aquifer. For example, Lake No. 12 stores runoff from the surrounding bedrock sub-basin and discharges it through a wetland to the head of sub-basin R7A. There does not appear to be any outwash aquifer in sub-basin R8, so this water is applied in the model as a source of recharge to sub-basin R7A.

Retreat Lake is considered to be a perched water body because it appears to be physically isolated from the underlying aquifer, due to a inferred layer of till or other fine sediments. It accepts surface water runoff from the surrounding sub-basin (R6) and discharges overflow via a small stream that enters a sinkhole in sub-basin R5B, with that water assumed to recharge the underlying shallow outwash aquifer.

Other water bodies in the Rock Creek catchment include Hidden Lake, Crow Marsh, and Cranberry Marsh (see Figure 3), which appear to be perched or isolated from the underlying aquifer. However, their role in water storage and groundwater recharge is reflected by their inclusion in the HSPF modeling (Appendix C) as permanently saturated soils (i.e., wetlands).

Ravensdale Lake, which is outside catchment modeled in HSPF but is within the ModFlow modeling domain, functions somewhat differently, as it appears to be in direct hydraulic communication with the aquifer (GeoEngineers 2000). Groundwater lakes like this can be represented by using artificially high conductivity values to flatten the water table locally within ModFlow. However, Ravensdale Lake has not been represented explicitly in the ModFlow model, since the effect would be local and would be constrained by the lower aquifer

conductivity of the rest of the Ravensdale aquifer channel upstream and downstream of the lake.

The Cedar River represents a major downgradient sink that forms the northern hydrologic boundary of the model domain, as described above in Section 2.2. Groundwater discharge occurs as baseflow from the aquifer and is simulated in the model as a constant-head boundary using the approximate water surface elevation for the river.

### 2.4.3 Groundwater Withdrawals

Conceptually there are three categories of groundwater withdrawals occurring in the Rock Creek catchment;

- City of Kent groundwater withdrawals at the Clark Springs Facility;
- Community Water Supplies (Non-exempt wells); and
- Residential Water Supplies (Exempt wells).

Withdrawals by the City of Kent are defined within the model as specified flows extracted from the aquifer at the Clark Springs Facility, based on the historical records maintained by the City of Kent since 1985. These were reduced to a long-term average rate for the steady-state model (4.0 cfs) and a set of monthly average values for the transient model (see Table 4).

Community wells and non-exempt wells make up the remaining known groundwater extractions, mainly from the upper catchment. An analysis of the probable extraction quantities is presented in Appendix E. However, most of the water extracted is returned to the aquifer as infiltration or percolation from septic drainfields, since the area is not sewered. The balance represents truly consumptive use by residents and other users within the basin, and is estimated to be on the order of 15 percent. Based on estimates presented in Appendix E, this represents approximately 0.3 cfs for current (1999) population levels. The associated net loss is small in comparison to the total amount of water moving through the Rock Creek aquifer system at any given time. The total flow is estimated through the modeling process to be around 30 cfs, and it has not been explicitly accounted for in the ModFlow model.

## 3.0 COMPUTER CODE DESCRIPTION

The computer code selected for this project was ModFlow, the USGS modular three-dimensional finite-difference computer code (MacDonald and Harbaugh 1988) that is capable of simulating steady-state and transient groundwater flow and hydrologic budgets in a range of aquifer types. Visual ModFlow (Waterloo Hydrogeologic 2000), a bundled software package containing ModFlow together with pre- and post-processing capabilities, was the version of the model employed for this project.

ModFlow uses finite-difference discretization of the aquifer system within the model domain, and a block-centered formulation to solve the differential equations governing groundwater flow. The mathematical model simulates flow indirectly by means of governing equations, which describe the spatial relationship between water levels, inflows and outflows, and aquifer properties. The model is based on the governing equations for anisotropic, heterogeneous steady, and transient groundwater flow, which are implicitly considered to provide a reasonable representation of the physical processes that occur in a natural system.

Discretization of the aquifer system within the model domain is the process by which the plan area of the modeled aquifer is divided up into a series of square cells. Aquifer properties, inflows, and outflows are specified for each cell. Within the numerical model, the complex relationships between groundwater flows, aquifer parameters, and groundwater levels (or hydraulic heads) are expressed in the form of a large matrix equation, which is then solved in terms of the groundwater heads in each cell of the model. The result is a distribution of groundwater heads (or water levels) throughout the model domain, which can then be compared with water levels observed in wells located at corresponding positions within the aquifer. A comparison between the simulated and observed water levels represents one measure of the success or calibration of the model, as discussed in Section 5. Additionally, ModFlow calculates an overall water balance for the model based upon the final groundwater head distribution, as well as inflows and outflows at hydrologic boundaries established in the model.

### *3.1 Assumptions*

The computer code (ModFlow) and our conceptual model used to develop the groundwater flow model representing the Rock Creek catchment are based on

several assumptions. The first two assumptions are inherent in unconfined groundwater modeling efforts while the others are specific to this model:

- Darcy's Law is applicable;
- Groundwater flow in an unconfined aquifer is adequately characterized by the Continuity and Boussinesq equations;
- The shallow aquifer, comprised of multiple coarse- and fine-grained glacial units, behaves as a single unconfined aquifer;
- The hydraulic parameters of the various glacial units within a specified area are homogeneous and isotropic at the scale represented by the corresponding modeled cell area; and
- Recharge occurring within each sub-basin is uniformly distributed across the sub-basin, or the adjacent down-slope sub-basin in the case of hillside runoff and interflow.

These assumptions place certain inherent limitations on the ability of the model to represent physical conditions at a given location and time. The limitations inherent to the ModFlow code are discussed in the following section; the resulting limitations of the calibrated Rock Creek model are discussed in Section 7.0 of this report.

## *3.2 Computer Code Limitations*

As with most mathematical representations of real world systems, the ModFlow code has its limitations. However, independent calibration and verification of the computer code have shown that, when sound solution techniques are employed, these limitations can be eliminated and/or kept below permissible thresholds. Some of the significant limitations in this modeling effort are described below.

### 3.2.1 Drying of Cells

ModFlow allows a cell within the model to lose water until it dries out completely. This is analogous to the water levels dropping in a part of the aquifer to the point where the saturated thickness drops to zero. However, upon drying out, ModFlow treats the once active cell as an inactive cell for

subsequent computations. It no longer allows flow through the cell, even if water levels around the cell want to rise and "re-wet" it. More critically, any recharge applied to the cell is subsequently lost to the model, with important consequences to the overall water balance and subsequent reliability of the simulation.

Visual ModFlow does contain a cell re-wetting package; however, due to model instability associated with this package, we elected not to use this option. Loss of recharge to the model as the result of dry cells can be circumvented by creating a second layer and selecting the option that applies the recharge to the uppermost active cell, therefore allowing the upper cell to go dry yet maintaining the areal recharge distribution. We have incorporated this technique, as discussed in Section 4.1.

### 3.2.2 Discretization of Time and Space

Subdivision of both time (transient analyses) and space (the model domain) are constrained by the limits of the computer code as well as computing efficiency. The preprocessor we used (Visual ModFlow) is constrained to 499 rows, 499 columns, and 60 layers. With the capabilities of today's computers, computing efficiency is usually not problematic; however, mathematical instability of the model may occur if discretization of time is not handled properly. We have followed the widely accepted discretization procedure outlined in Anderson and Woessner (1992).

Discretization presents a limitation in terms of the way in which the hydraulic properties of the aquifer are represented. Within each cell of the model, hydraulic properties are defined to be uniform, and the resultant head calculated for a given cell in the model is applied over the full square area of the cell, and for the duration of each timestep. In reality, the hydraulic properties will likely vary broadly over the scale of each cell, and the water level (in an unconfined aquifer) will form a complex parabolically curved surface that is continuously varying in time and space. Cell sizes are chosen as an initial step in model construction (see Section 5), and may be varied by the modeler to suit the conditions and performance of the model.

### 3.2.3 Convergence

ModFlow solves the complex sequence of linear and non-linear equations that represent groundwater flow in the aquifer using an iterative solution technique

that proceeds by recalculating the entire solution for the model in a stepwise fashion until the difference between successive runs is below preset user-defined criteria. This process is called convergence. Since convergence is controlled by values of parameters set by the user (see Section 3.4) the degree of convergence relates to the overall accuracy with which the model solves the governing equations.

### 3.2.4 Model Layers

ModFlow provides the ability to subdivide the aquifer system into a series of layers. Layers are normally used to represent individual aquifers, which can be stacked vertically, and separated by less permeable formations (aquitards). For the Rock Creek model, the glacial outwash aquifer is relatively thin and has not been sufficiently investigated or mapped to allow reliable subdivision into more than one layer. Furthermore, wells drilled into the aquifer generally exhibit a single water level (rather than multiple heads at differing depths), suggesting that the aquifer can be adequately represented as a single layer within ModFlow.

To overcome the problem of drying cells in the Rock Creek model, the inclusion of a second layer, representing the bottom 6 feet of the overall aquifer thickness and with identical hydraulic properties to the layer above, greatly improved the stability and convergence of model runs.

## *3.3 ModFlow Modeling Packages*

Visual ModFlow incorporates several predefined modules or packages, which aid the user in representing specific aspects of real-world aquifer systems within the model. Several of these packages are based upon similar concepts and can be substituted for one another while yielding very similar results. Listed below are brief descriptions of the packages relevant to the Rock Creek catchment model.

### 3.3.1 Well Package

The well package provides a method for representing a water supply well in the model, it can also be used for adding or removing water from the model in other ways, such as to represent a spring or a well field in very coarse gridded models. Well characteristics, such as a point source or discrete pumping depth, are not recognized by ModFlow. The flux is added or removed from the center of the cell and across the entire thickness and area of the cell. The well package was

used to represent the infiltration gallery and the three pumping wells located at the Clark Springs Facility, as described in Section 4.3.2.

### 3.3.2 River Package

The river package was designed to mimic a stream or river that is hydraulically connected to the surrounding aquifer. Input data for the river package consist of river stage elevation, river bottom elevation, and a streambed conductance term, which represents the resistance to flow between the river and the aquifer. This package is capable of representing a losing or gaining river reach; however, for losing reaches, the seepage out of the river is independent of the river's discharge; therefore, the potential exists for the river to lose more water to seepage than it is actually conveying in the river bed. The physical dimensions of the river and the stage-discharge relationship must be incorporated into the model at every river node. Often, this level of data is not available, as is the case for much of the Rock Creek watercourse. The streambed conductance is theoretically related to the vertical hydraulic permeability of the streambed sediments but in practice this becomes a calibration parameter that is adjusted to give the best match between observed and modeled stream-aquifer behavior.

Due to the potential for excessive creek discharge occurring when groundwater levels drop below the creek bottom elevation, as Rock Creek does below the Clark Springs Facility, the river package was not incorporated into the Rock Creek catchment model, as the resulting model behavior of Rock Creek would not be consistent with our observations - namely that the streamflow in this reach is essentially perched upon lower-permeability streambed sediments that tend to isolate the streamflow from low groundwater levels, substantially limiting stream losses during periods of low flow that would otherwise be significant if calculated using the river package (see Appendix E for further discussion). Therefore, a decision was made to use the drain package (see below).

### 3.3.3 Drain Package

The drain package represents a head-dependent flux out of the model from a given cell. The flux rate is determined by the head difference between head levels in the surrounding cells and a user-specified elevation for the drain. The flux rate can also be modified or throttled by a conductance term that can be used to represent hydraulic entrance or seepage losses at the drain. Unlike the river package, the conductance value associated with the drain package is not derived from measured physical properties such as streambed permeability,

thickness, and width because the bulk of flow to the drain likely occurs as horizontal seepage through the aquifer, rather than vertical flow through the streamed (see Figure 5). Groundwater discharge that becomes baseflow in Rock Creek within the vicinity of the Clark Springs Watershed was modeled using the drain package by defining drain cells along the course of Rock Creek, and interpolating between detailed topographic survey contours in this area to estimate streambed elevation. In the ModFlow model, baseflow discharge occurs from the main (upper) layer of the model cell, which represents the water table aquifer.

### 3.3.4 Solver Package

Visual ModFlow includes a number of optional solvers. The model solver selected for the Rock Creek ModFlow modeling was the Preconditioned Conjugate-Gradient Package (PCG2). This solution technique solves simultaneous linear and non-linear equations produced by the model via the preconditioned conjugate-gradient method. This solver package was selected based upon its computational efficiency and widespread use among groundwater modelers. The theory of this method and pertinent information regarding this solution technique are presented in Visual ModFlow user manual (Waterloo Hydrogeologic 2000).

### 3.3.5 Zone Budget Package

In addition to the overall water balance calculated by ModFlow, Visual ModFlow has incorporated a zone budget package. This package calculates water balances within sub-regions of the model domain as well as for the entire model. Sub-regions or even single cells within the model can be specified as zones, thereby, providing detailed site-specific water balance data for steady-state or transient solutions.

### 3.3.6 Layer Type

ModFlow requires individual layers within the model to be classified as one of the four predefined layer types corresponding to the aquifer conditions listed below:

- **Type 0.** Confined;
- **Type 1.** Unconfined — can only be assigned to the top layer;

- **Type 2.** Confined/unconfined – transmissivity is held constant where as the storativity may alternate between confined and unconfined values; and
- **Type 3.** Confined/unconfined – transmissivity of the layer can vary depending on the saturated thickness and the storativity may alternate between confined and unconfined values.

The layer types assigned to the Rock Creek model were Type 1 and Type 3 for the top and bottom layers, respectively. Based upon our conceptual model, we designated the bottom layer as Type 3 to accommodate fluctuating water levels in the bottom layer during transient simulations.

### *3.4 Settings and Model Convergence Parameters*

As described in Section 3.3.4, the solution technique executed by ModFlow was the PCG2 Solver. This solution technique requires input of user-defined constraints (listed below) to control the accuracy and convergence of the solution.

- Maximum Number of Outer Iterations;
- Maximum Number of Inner Iterations;
- Preconditioning Method;
- Head Change Criterion for Convergence;
- Residual Criterion for Convergence; and
- Printout Interval.

As a rule of thumb, the head criterion should be one to two orders of magnitude lower than the level of accuracy desired in the head results. Alternatively, the error criterion for the water balance of the model is another assessment of the model's accuracy where percent discrepancies less than two are considered acceptable. Historically, the value of the head change criterion was viewed as representing the model's overall accuracy; however, with the expanded use of variable grid spacing and more sophisticated solver packages (i.e., PCG2), the model's calculated water balance is considered to be a better representation of the model's accuracy. Table 1 lists the user-defined convergence parameters used for the steady-state and transient solutions.

# 4.0 MODEL CONSTRUCTION

The data processing required to construct the Rock Creek ModFlow model as well as analyze results was accomplished by using the pre- and post-processing capabilities of Visual ModFlow. Data manipulation beyond the capabilities of Visual ModFlow was accomplished by incorporating additional software packages, including Geographic Information Systems (GIS) and Surfer. For ease of model development, the grid and corresponding input parameters are in metric units. However, for presentation purposes, output from the model has been converted to English units.

## *4.1 Model Domain*

The model domain was referenced to the recent topographic survey data acquired by Triathlon for the City of Kent. The GIS coverages (geology, watershed boundary, and topography) derived from or integrated with the survey data were imported from GIS to ModFlow as base maps. The base maps provided overlays for the development of the model grid and for assigning boundary and aquifer parameters.

ModFlow requires the area/aquifer of interest to be divided or discritized both horizontally and vertically into cells. Areal discritization of the model grid is shown on Figure 6, note the increased density of rows and columns to allow more detailed simulation of gradients and flows in the vicinity of the Clark Springs Watershed. Cell dimensions ranged from 40 feet at the Clark Springs watershed to 180 feet near the model boundaries, giving a reasonable compromise between model precision and speed of execution. Visual ModFlow's smoothing algorithm was employed to adjust spacing between rows and columns so that the expansion factor between successive adjacent cells remained below 1.5, where numerical instability becomes problematic.

Conceptually, we have assumed that the real aquifer system can be modeled adequately as a one-layer unconfined system; however, due to cells drying out, the aquifer system was divided into two layers with a uniform bottom layer thickness of 6 feet. The aquifer bottom elevation or bedrock surface was derived from well logs previously synthesized by Robinson and Noble (1995) and Hart Crowser (1996). These data in conjunction with user-defined data (exposed bedrock) were gridded and contoured by Surfer and imported to ModFlow.

For transient simulations, ModFlow requires time to be discretized into a series of stress periods, which are further sub-divided into time steps. Time steps provide a means for incorporating stresses gradually. We established a one-month stress period for the transient simulations of the Rock Creek catchment model. Kresic (1997) states that transient calibration based on monthly values is preferred over daily or weekly data since groundwater systems usually react with a certain delay to surface stresses. In addition, monthly data enable comparative analysis of seasonal influences, which can be important for long-term predictions.

## *4.2 Hydraulic Parameters*

Hydraulic parameters specified as variables in the model are physical properties of the aquifer that define how an aquifer will react when placed under a hydraulic stress, specifically how the aquifer transmits and stores water. These properties vary from location to location, but do not generally change over time. The values for the parameters discussed below are the final calibrated parameters used in the steady-state and transient solutions.

### 4.2.1 Hydraulic Conductivity

Initial hydraulic conductivity values assigned to the model were derived from Robinson and Noble (1995) for the majority of the model domain and from GeoEngineers (2000) for the area north of Ravensdale Ridge. Adjustments to the hydraulic conductivity parameter during calibration were kept within documented ranges (Domenico 1990) for the assigned aquifer materials. Areal distribution of the calibrated hydraulic conductivity values is shown on Figure 7. Isotropic conditions were assumed throughout the model, with uniform values of hydraulic conductivity assigned to the zones shown on Figure 7. The final set of calibrated hydraulic conductivity values is generally within the ranges quoted by the above sources and covers a narrower spread. This is consistent with the larger scale over which these average values are applied within the model, in contrast to what are spot or localized and, therefore, potentially highly variable values obtained in the field.

The distribution of hydraulic conductivity values reflects the distribution of high permeability glacial deposits within the high-energy depositional environments of the main aquifer channels at Rock Creek and Ravensdale, as well as in the area of Georgetown. Elsewhere, lower values were required in the model to maintain consistent water levels; if higher values were used, the water table would drop

to an elevation that was too low. West of Clark Springs, the lower values reflect the reduced energy of the depositional environments beyond the range front, which is consistent with finer grained sediments being deposited on the Covington outwash plain.

North of Clark Springs, anomalously low values of conductivity were required to represent the steep inferred water table that provides the transition between elevated bedrock forming the base of the aquifer system in the upper catchment, and the much lower alluvial floodplain associated with Cedar River. Although low hydraulic conductivity is consistent with an inferred till-like substrate for Rock Creek that limits stream losses in the lower reaches, the steep hydraulic gradients may reflect more complex groundwater conditions associated with the southern wall of the Cedar River valley that is largely obscured by sediments. More information on this is presented in Appendix E.

### 4.2.2 Specific Yield

The aquifer's ability to take water into or release water from storage defines the specific yield for an unconfined aquifer. Typical values for specific yield associated with the materials comprising this aquifer system range from 0.1 to 0.3. The model is relatively insensitive to variations of specific yield within the normally occurring range of 0.1 to 0.3, so a value of 0.2 for specific yield was assigned for the entire model.

## *4.3 Sources and Sinks*

The driving force for this groundwater system is precipitation, which varies substantially across the catchment. The rainfall distribution, temporal variability, and orographic effects associated with the Cascade foothills, located east of the model, were addressed by MGS Engineering Consultants using the PRISM model (as described in Appendix C of the BA), for developing time series inputs to the HSPF modeling efforts. Groundwater recharge values were then determined within HSPF and used as input to define the recharge distribution in ModFlow.

### 4.3.1 Aquifer Recharge

Recharge data derived from HSPF modeling performed for the Rock Creek BA (See Appendix C) were distributed areally over the ModFlow model domain within the corresponding HSPF sub-basins (see Figure 6). Sub-basins as defined

for HSPF modeling have one or two sources of recharge depending on their location. Sub-basins that border till-capped or bedrock hills have one source from direct precipitation in the sub-basin and a second source (interflow) emanating from the bedrock and glacial till-capped hills (see Figure 2). The additional recharge was distributed equally across each adjacent sub-basin.

Recharge values for regions of the model located outside the surface water basin were estimated. Estimation of these values took into account orographic effects and surface area of surrounding till-capped hills if present. Table 2 lists the long-term average recharge values per sub-basin as derived from HSPF model simulations of the period from 1944 to 1998, as used in the steady-state simulations. Transient solutions incorporated monthly values for recharge rates calculated directly from the HSPF modeling results; recharge estimates for areas outside the surface water basin followed the same procedure used for the steady-state estimates.

### 4.3.2 Clark Springs Facility

Groundwater withdrawals from the Clark Springs Facility via the infiltration gallery and production wells were modeled using a series of sinks or points of withdrawal with specified outflows in the approximate location of the infiltration gallery. Modeling the infiltration gallery in this manner adequately represents the withdrawal mechanism since ModFlow removes the flux from the center and across the entire thickness of the cell. A long-term average value of 4.8 cfs was used in the steady-state model, and averaged monthly values for the 1998 water year (ranging between 4.9 and 8.0 cfs, as listed in Table 4) were used in the transient model.

## *4.4 Boundary Conditions*

Boundary conditions applied to the model control and regulate the inflow, outflow, and general flow system for groundwater represented within the model. Constant head boundaries applied to parts of the outer edge of the model to control overall head levels while minimizing effect on the solutions. The boundary conditions applicable to this model are addressed in detail in the following sections and displayed visually on Figure 6.

### 4.4.1 No Flow Boundary

Model cells occurring outside the aquifer boundary were inactivated thereby creating a no flow boundary around most of the aquifer (see Figure 6). ModFlow interprets this type of boundary condition as an impermeable barrier and directs flow parallel to the boundary. The model cells along the perimeter of the overall rectangular model grid are by default no-flow boundaries unless another boundary condition (as described below) has been specified for the perimeter cells.

### 4.4.2 Constant Head Boundary

Constant head cells were assigned along the west and northwest boundaries of the model to simulate conditions that control downstream water levels in the outwash aquifer. This provides a discharge mechanism for groundwater flow through the model. The western edge of the model domain is defined by a straight line of constant head cells that represent Lake Sawyer and progress northward as water table elevations within the downgradient aquifer.. Constant head cells also define the northwest boundary, but represent generalized head levels of the Cedar River. A gap in defined boundary conditions north of Wilderness Lake allows the groundwater contours to turn in this area, reflecting the flow of groundwater toward the Cedar River.

### 4.4.3 Rock Creek Headwaters

Head-dependent boundary cells in the form of drain cells were used to simulate the headwaters of Rock Creek and the stream channel at Clark Springs. Our conceptual model infers that Rock Creek is perched on low-permeability sediments downstream of the Clark Springs Watershed and loses very little water prior to its confluence with the Cedar River. Therefore, drain cells adequately represent the head-dependent discharge of groundwater to Rock Creek extracting water from the model to simulate baseflow, but preventing the loss of streamflow to the aquifer, as should be the case for a perched creek system (see Figure 5).

## *4.5 Water Balance*

The water balance of a groundwater model provides a means for evaluating the inflows and outflows of the model for steady-state solutions. In transient simulations, uptake and release of water to and from storage are also included in

the water balance. Ideally, the percent discrepancy between the inflows and outflows should be zero, but current modeling research and literature show that an error of less than 1 to 2 percent is acceptable, which we have adopted for the Rock Creek model.

In addition to the overall model water balance, we have established localized water balances within key areas of the model using the zone budget package. Localized water balances provided a means for quantifying the flow quantities into and out of the intermediate bedrock channels as well as providing a check during calibration efforts.

## 5.0 CALIBRATION

Groundwater models in general are calibrated by matching computed heads to observed groundwater levels in the natural system. The level of calibration, and thereby the ability to accurately predict future conditions, is dependent upon the conceptual model and available information used to construct and calibrate the model.

### *5.1 Selection of Calibration Targets and Goals*

The primary calibration goal was to simulate the regional water table configuration for the basin as originally developed by Robinson and Noble (1995). They created a generalized regional water table map by synthesizing well data from 463 wells. For wells completed in the shallow aquifer, water levels (if more than two), were averaged and rounded of to the nearest 10-foot interval. Elevation contours at a 25-foot interval were then drawn by hand. The large number of wells used to construct the map tends to compensate for seasonal variations, the effects of pumping, and elevation errors. The position of the contours will adjust slightly with seasonal changes, but the overall shape of the surface will not. Robinson and Nobel's generalized contour map is presented on Figure 8.

The secondary calibration goal was to simulate transient groundwater conditions within the basin. Calibration targets for the transient analysis consisted of water level monitoring records obtained by the City of Kent from six of their WHPA monitoring wells located throughout the model domain, as shown on Figure 6. Emphasis was placed on calibrating to three of the WHPA wells–the Bridal Trails well, Bremmeyer Logging well, and the Bremmeyer Community well. These

provide a broad spread of areal coverage within the central area of the model domain, in the area upstream of Clark Springs.

Monthly transient groundwater levels were simulated using ModFlow for the 1998 water year — the period during which WHPA monitoring records and the HSPF-derived recharge data overlap.

## *5.2 Steady-State Solution*

The steady-state solution represents a generalization of the aquifer response to long-term average recharge rates and stresses. It does not represent conditions over any given time period, but rather uses average values for inputs and outputs that produce an average depiction of the water table, which can then be compared with the average water level map obtained for the model area. This solution provides an important intermediate step to evaluate our conceptual flow paths, to assess the model's response to given stresses, and to check on the overall water balance for the modeled aquifer system.

The steady-state solution is an integral step prior to introducing the variable time-dependent recharge inputs that define the transient nature of the groundwater system occurring in the Rock Creek catchment. The steady-state solution of the general water table configuration is presented on Figure 9.

Model calibration required to generate this configuration was substantial due to aquifer geometry in the upper catchment and the overall high transmissive nature of the aquifer. Aquifer thickness and hydraulic conductivity were the primary parameters adjusted during the calibration process. Generally, calibration progressed from east to west across the model domain until a stable and consistent flow system was achieved and the number of dry cells generated was eliminated or minimized.

Recharge input data for the steady-state solution are average values (1944 to 1998) for each sub-basin as derived from HSPF, which incorporated the 1968 land use for the entire period of record. Magnitude and areal distribution of hydraulic conductivity were manipulated first in calibrating the model. Aquifer thickness was only adjusted when the required changes to hydraulic conductivity would approach or exceed the upper limits of documented values for the representative aquifer materials.

Only in one area was a conscious effort made to restrict the model to a specific hydraulic conductivity distribution, the area prior to the bifurcation into the Rock Creek and the Ravensdale Channel. The hydraulic conductivity parameter in this area was uniformly distributed across the aquifer except for a wedge of material north of Ravensdale Ridge where GeoEngineers (2000) documented a lower conductivity material, based on its investigations of the McCann property. Constraining the hydraulic conductivity in this area to a uniform distribution eliminated the potential for development of a preferential pathway down only one of the intermediate aquifer channels. The conductivities assigned in the Rock Creek and Ravensdale aquifer channels were based on calibrated water levels. But, due to reduction in channel width, the values in the Rock Creek aquifer channel are substantially larger.

Upon establishing a stable flow system within the model, sinks representing withdrawals from the Clark Springs Facility and baseflow discharge to the headwaters of Rock Creek were introduced. Their effects on the model required secondary calibration efforts, primarily adjustments to hydraulic conductivity and aquifer depth in the Rock Creek aquifer channel. High conductivity values associated with the Rock Creek aquifer channel did not promote groundwater levels high enough to drive enough groundwater into the drain cells representing Rock Creek. To circumvent this, adjustments were made to the base elevation of the aquifer channel based on a review of borehole logs from earlier investigation of Clark Springs Watershed (Robertson and Anderson 1951) rather than representing the area as a uniform continuous aquifer channel. The change reflects the presence of a till wedge that appears to effectively reduce the depth of the aquifer channel, and may play a part on creating the springs at this point in the Rock Creek system.

Extraction rates from the Clark Springs Facility were simulated at 4 cfs, which corresponds to the long-term average production rate for 1944 to 1998 period of record. Calibration of baseflow discharge to Rock Creek was not a major focus for the steady-state solution due to the difficulty in separating baseflow from runoff over multiple years in the period of record and obtaining one definitive value, but the targeted range of 4 to 6 cfs was obtained.

### 5.2.1 Calibrated Simulation Results

Figures 8 and 9, respectively, show the water table map constructed by Robinson and Nobel and the groundwater elevations generated from the steady-

state solution. The modeled water table provides a reasonable representation of the observed water table map, but with some localized differences:

- Water levels in the model are reduced through sub-basin R7A, which represents an old glacial outwash channel, and also receives substantial runoff and interflow from the adjacent Ravensdale Ridge. It also represents a slight trough through which the upper stream channel of Rock Creek flows. High aquifer transmissivity was required in this area to carry away the high recharge rates associated with runoff and interflow from the adjacent Ravensdale Ridge.

- The hydraulic gradient is flattened through the central area east of Georgetown. Again, relatively high values of hydraulic conductivity were required in the model to convey the amounts of groundwater flow recharging the aquifer in the east, and discharge to Rock Creek in the west.

- Water levels at the western end of the Clark Springs Watershed are somewhat lower in the model simulation. These appear to reflect conditions noted by Robinson & Noble in October of 1994 (see their Figure 3.21).

The water balance data for the converged steady-state solution is presented in Table 6. The model represents our conceptual model of the general flow system quite well. Precipitation-derived recharge (33 cfs) is the dominant inflow to the model. This value is slightly higher than the total basin-wide recharge value for the HSPF modeling due to our expanded model domain. Model outflows include wells (4.0 cfs) representing withdrawals from the infiltration gallery, and drains (4.8 cfs) representing baseflow discharge to Rock Creek. Additional outflows occur at constant-level cells (24.9 cfs) consisting of two components; groundwater discharging to the west as through flow to the downgradient aquifer (17.6 cfs), and groundwater discharging northward to the Cedar River (7.3 cfs).

Within the calibrated steady-state model, the distribution of groundwater flowing out of the upper catchment to the intermediate aquifer channels was: Rock Creek Channel (54 percent), Ravensdale Channel (41 percent), and the Landsburg Channel (5 percent).

## *5.3 Transient Solution*

The transient solution was calibrated to the target water levels monitored in the WHPA wells and to Rock Creek flow data previously described in Section 5.1 for the 1998 water year. The rapid response time between the aquifer and precipitation events coupled with the aquifer's high transmissivity required additional calibration of hydraulic conductivity values beyond that performed for the steady-state solution. Additionally, minor modification to drain cell elevation and conductance values was also required.

Due to the time dependency inherent to transient analyses, accurate initial water levels and a period of simulation prior to the period of interest are usually required to ensure that prior storage adjustments are appropriate for the simulation period of interest. We have provided our best estimate of initial water level conditions and incorporated one full year of simulation time prior to the 1998 water year to reduce the effects of prior storage in the aquifer.

### 5.3.1 Calibrated Simulation Results

The transient solution produces a general water table configuration similar to the steady-state solution presented on Figure 9. Measured and simulated transient water level responses for the WHPA monitoring wells during the 1998 water year are presented on Figures 11 through 13. As shown on these figures, the water levels are consistently overestimated for the first third of the year and then match reasonably well for the remainder. Generally, the match between simulated and measured water levels improve as the monitoring well locations get closer to the Clark Springs Watershed. This is most likely a reflection of increased data quantity and quality for the representation of the aquifer in this area. Overestimation of modeled water levels during the first third of the year is attributed to uncertainty in the appropriate initial water levels specified in the model.

The model's water balance and groundwater flow distribution as related to the intermediate aquifer channels for the 1998 water year are summarized in Table 4. As shown in Table 4, the model's overall water balance for all the stress periods is very good (0.00 percent). The model's division of groundwater flow down the intermediate aquifer channels is representative of our conceptual model. The average groundwater flow down the Landsburg aquifer channel is 7.2 percent, with the remaining groundwater flow almost evenly split between the Rock Creek aquifer channel (51 percent) and Ravensdale aquifer channel (49

percent). However, during the dry season (July through September 1998) the percentage of flow down the Rock Creek aquifer channel is 1 to 2 percent less than flow entering the Ravensdale aquifer channel.

As shown on Figures 14 and 15, which provide results from the 1997 and 1998 water years, recharge to the basin in 1998 was substantially less than that of the preceding year. Water balance results from 1997 indicate that flow down the Rock Creek aquifer channel under the high recharge rates was greater (average 54 percent) than the flow directed down the Ravensdale aquifer channel.

### 5.3.2 Sensitivity Analysis

The only model input parameters that were changed during the calibration process were hydraulic conductivity and specific yield. A sensitivity analysis of these parameters was performed on the transient solution by varying hydraulic conductivity values (±25%) and specific yield by (±50%). The results of this analysis are presented in two sets of graphs. Figures 14 and 15 display the model's sensitivity to hydraulic conductivity and specific yield as they relate to effects on discharge to Rock Creek, whereas the second set of graphs, Figures 16 and 17, display the effects on the water table. The water levels in the Bremmeyer Logging and Bremmeyer Community observation wells responded in a similar manner. The modeled responses created by varying hydraulic conductivity and specific yield do not deviate from standard hydrogeologic principles; however, several model characteristics are worth noting:

- Changes to specific yield produce a more dramatic effect on water levels and discharge to Rock Creek as compared to changes in hydraulic conductivity; and

- The sensitivity of the model to both hydraulic conductivity and specific yield increases during periods of low recharge. This effect is evident on Figures 14 and 15 where recharge for the 1998 water year was substantially less than the previous year.

The other uncertainty that would have a substantial influence on the model is the amount of groundwater recharge, which cannot be directly measured. The calibrated model relies heavily on the recharge derived from the HSPF model, which is assumed to be of a higher reliability than the aquifer parameters. The amount and distribution of recharge dictate to a significant degree the

distribution and calibrated values of conductivity required to match modeled and observed water levels across the catchment.

## *5.4 Model Application Verification*

To test the model's ability to simulate imposed hydraulic stresses other than those encountered during the calibration process, we set up the model to simulate the system test conducted the Clark Springs Facility by Hart Crowser in Spring 2001. The calibrated transient model, operating on monthly stress periods, was configured to accommodate daily stress periods; thereby, allowing detailed input of stresses created by changes in flow at the infiltration gallery, as well as detailed data output from the drain cells for comparative purposes. Groundwater recharge data and initial heads from May 1994 were used for this simulation due to HSPF-derived recharge data ending in 1998. Although the precipitation and water levels are similar for May of 1994 and 2001, the overall effect due to minor discrepancies between the years will be negligible since the stress periods were reduced to daily intervals.

### 5.4.1 Simulation Results

The converted (monthly to daily) transient model successfully simulated the May 2001 Clark Springs Facility system test. A comparison of measured vs. simulated water levels observed during the systems test is presented on Figure 18 for monitoring well MW-1. The simulated transient response provides a reasonable fit with respect to magnitude and shape of the drawdown and recovery phases. Similar responses were observed in monitoring wells MW-2, OBS-2A, and MW-4 although the overall difference between simulated and observed drawdown response decreased with radial distance from the infiltration gallery.

Acceptable matches to measured water levels in surrounding wells were obtained by introducing a 9-day antecedent period simulating the cyclical on/off operation of the infiltration gallery prior to the system test itself. Final simulations consisted of simulating operations of the infiltration gallery (at average discharge rates for that period) for the 9-day period operating at an average discharge rate, followed by 3 days of simulation with detailed discharge input representing the system test.

Hydraulic conductivity and specific yield values used in the simulations were varied in the vicinity of Clark Springs in an attempt to provide a better match to observed water levels; however, only specific yield produced an appreciable

effect. Significant reduction of specific yield for the area surrounding the infiltration gallery was required to create the rapid response exhibited on Figure 18. Specific yield was reduced to very small values (0.0001) in these model runs. Such values can occur in unconfined aquifers due to the phenomenon of delayed drainage or delayed yield. Rapid changes in water levels, as seen in the cyclic operation of the Water Supply System, may occur faster than changes in the water table within the sediments as drainage from pore spaces lags behind, giving rise to the delayed drainage effect. This is suggested by the low value of specific yield needed to simulate the short-term aquifer stresses associated with the system test.

Although simulated heads matched the Systems Test data, the creek response only accounted for approximately 30 percent of the facility discharge, whereas analysis of the test data indicates the creek response to be approximately 90 percent (see Appendix E). This suggests that further work is needed to refine aspects of the model in this area, and may highlight limitations of the drain package for simulating short-term changes in flow between the aquifer and the creek.

The simulated head and creek response from calibration indicates that the model is functioning properly when viewed on the regional level. Additionally, the simulated head data from the systems test matches very well on a local scale. The discrepancy of the creek response between the calibration runs and the systems tests run indicate that the mechanism for groundwater entering Rock Creek within the Clark Springs Watershed is not fully understood. An isolated creek zone that intercepts a preferential groundwater pathway could provide the creek response noted in the systems test and still maintain the same response that our representation of the creek provided in the calibration runs.

Such changes to the modeled aquifer configuration in the area of the infiltration gallery do not appear justified based on the data available. The rapid response suggests that the aquifer may be even narrower than it has been modeled in this area, which would in turn require substantially higher values of aquifer transmissivity to convey the quantities of water recharged upstream without causing heads in the model to rise to unrealistic levels through the Clark Springs Watershed.

## 6.0 PREDICTIVE SIMULATIONS

The calibrated model could be used in support of the proposed Clark Springs Habitat Conservation Plan (HCP) to study the potential effects of alternative production scenarios for the Clark Springs Facility. The impacts of higher and lower production rates could be examined, especially their effects on baseflow discharge that maintain the downstream flow in Rock Creek.

## 7.0 MODEL LIMITATIONS

The groundwater model developed in this work scope is reflective of our conceptual model of the Rock Creek catchment. As with most conceptual and physical models, one unique solution is rarely obtained that fits all the data; therefore, it is within reason to assume the groundwater model presented here is not unique in its solutions. However, based on available data, prior experience in the project area, and information gained during the development of the groundwater model, we feel the model represents a credible and unbiased representation of the hydrogeology in the basin. The following sections describe in more detail areas in the model may be unduly affected by the availability of data and/or where the conceptual model may have alternative scenarios.

### *7.1 Model Uncertainty*

Although site-specific data exist for parts of the upper catchment, some uncertainty still exists with respect to the detailed hydrogeology of the system. Model development for this work scope required these uncertainties to be addressed using best judgment; however, our conceptual model likely represents only one solution scenario. Other plausible scenarios could be developed from the data.

Development of the input data is predicated on the analysis and interpretation of various geologic events that have contributed to shaping the bedrock and depositing the overlying sediments that define the nature and extent of the shallow aquifer. Likewise numerous theories and opinions have been developed with respect to preferential/distinct glacial outwash channels and localized drift plains within the catchment. Aspects of these interpretations and uncertainties that affect the construction of the model include aquifer thickness; hydraulic conductivity; and basin/sub-basin boundaries; aquifer discharge areas; and groundwater recharge.

### 7.1.1 Aquifer Thickness

The thickness and fines content of the aquifer material play a very important role in the storage and transmission of groundwater to the Clark Springs Watershed. The thickness and makeup of the aquifer vary across the upper catchment. Robinson and Noble (1995) believe that the aquifer thickness northwest of Lake Retreat may be so small that groundwater flow forms a thin horizon at the base of the aquifer that mimics the bifurcated patterns typical of overland flow with the potential of completely drying up in times of limited precipitation. However, south and slightly east of Lake Retreat, boring log data suggest the existence of a buried northwest trending geologic structure that potentially creates increased aquifer thickness to the west and a reduced aquifer thickness to the east. These variations created a sharp transition in the base elevations of the aquifer, and proved difficult to model, even with the added basal layer in ModFlow.

### 7.1.2 Hydraulic Conductivity

Hydraulic conductivity controls the transmissivity of the aquifer. Aquifer testing in the upper catchment is limited. Therefore, assignment of hydraulic parameters to various sections of the aquifer was based on the values required to achieve calibrated water levels in the model. The resulting conductivity distribution (Figure 7) represents some bias in the assignment of large-scale areas with uniform average conductivity that may or may not be representative of the aquifer. Additional modeling strategies (e.g., using an optimizing calibration algorithm such as PEST), could lead to a more detailed and variable conductivity distribution that provides better calibration with the observed water levels. This approach could be considered as a refinement for future modeling studies (see Section 7.2).

### 7.1.3 Catchment and Sub-Basin Boundaries

While the surface topography of the Rock Creek catchment has been redefined using the new survey data from Triathalon, surface contours in some areas of low topographic relief near the basin boundaries make a definitive delineation of the catchment difficult. This affects both HSPF and ModFlow, with uncertainty in the need to include or exclude recharge and potential surface flows from areas such as Cranberry Marsh, where the limits of the topographic boundary are not clearly defined by the ground surface contours.

Similar uncertainty exists in the northeast corner of the basin, where groundwater is known to flow northward in a more direct path to the Cedar River. Therefore, we excluded recharge and flow from a significant sub-basin (R3E) as described in Section 2.2. However, the boundaries of this area that should be excluded are subject to interpretation, and could have been chosen differently, with potential effects on the overall flow quantities generated in the upper catchment. Similar uncertainties apply to recharge and groundwater flow for sub-basin R3D.

### 7.1.4 Aquifer Discharge Areas

Three discharge outlets (Rock Creek, Ravensdale, and Landsburg aquifer channels) have been identified for groundwater flowing out of the upper catchment. The uncertainty associated with these discharge outlets is the percentage of flow directed down each aquifer channel. Quantification of these percentages is hampered by the uncertainty associated with the geologic conditions listed below which may or may not control flow into and/or through these aquifer channels.

Potential factors controlling groundwater flow into and through the intermediate aquifer channels include:

- Location of one or more discrete flow conduits comprised of very coarse and permeable deposits;
- Conductivity of the deposits inside and outside of discrete flow conduits; and
- Depth and width of highly permeable deposits if a discrete conduit exists.

Additionally, discharge may also be occurring throughout the entire Rock Creek catchment via downward movement of groundwater to the underlying bedrock and/or lower conductivity sediments. The quantity of such discharge is unknown and is not accounted for in the model, with the bedrock assumed to have a low hydraulic conductivity. If bedrock is assumed to have a hydraulic conductivity of between $10^{-8}$ and $10^{-7}$ cm/sec (0.00003 to 0.0003 ft/d), the approximate amount of loss due to deep groundwater seepage is estimated to be between 0.1 and 1.0 cfs. At higher values of permeability, such seepage losses could aversely affect the results of the model, but would need to be weighed carefully against uncertainties in groundwater recharge.

### 7.1.5 Groundwater Recharge

We have relied on HSPF modeling for derivation of recharge input data. Uncertainty associated with those techniques has been addressed in the HSPF Report (Appendix C of the Clark Springs BA); however, our use and distribution of the recharge data could affect modeling results. We have uniformly distributed runoff from till-capped uplands to adjoining sub-basins. In reality, the interaction between upland runoff and its initial contact with permeable outwash deposits is likely to be more complex and varied along the periphery of the outwash aquifer. Depending on the timing of the runoff and amounts, the distribution of the runoff to the aquifer could range from a time-lagged percolation down to the water table via unsaturated sediments in the vadose zone, to instantaneous capture by a very shallow groundwater table, which in some areas may contain highly transmissive surface sediments.

Timing associated with direct recharge and runoff generated by saturation of surface soils most likely plays an important role in distribution and fate of groundwater recharge. The use of a month-long stress period coupled with average monthly groundwater recharge inputs has constrained the flexibility of ModFlow for the transient simulations. Improved results may be obtained using shorter stress periods, but with the added risk of increased convergence problems.

## *7.2 Additional Studies*

The ModFlow model presented in this report represents a substantial improvement on the understanding of and ability to simulate groundwater flows in the Rock Creek catchment. However, model improvements could be achieved in terms of accuracy and representation of specific flow components through the evaluation and inclusion of additional model features, supported by additional field studies as outlined below.

### 7.2.1 Groundwater Recharge

The amount and distribution of recharge to the ModFlow model could be re-examined using a different rainfall-runoff model that is more suited to the physiographic and geologic conditions in the catchment that play a significant role in the generation of runoff.

### 7.2.2 Flow to Green River

The occurrence of groundwater flow to the Green River could be more significant than has been assumed. However, it would likely be very difficult to accurately quantify the amount of flow that is occurring. Visual flow estimates could be developed for springs and seeps that have been observed by the park ranger, and a further allowance for dispersed seepage losses through the rock wall of the Green River canyon could be made. Inclusion of this loss of flow in the model would result in reduced amounts of groundwater flow discharging through the three aquifer channels in the northwest of the catchment, and other calibration adjustments would be required to maintain groundwater heads and baseflow discharges.

### 7.2.3 Flow Split

Given the sensitivity of this issue, attempts should be made to field verify the amount of the flow split occurring down the three aquifer outflow channels from the upper catchment (Rock Creek, Ravensdale, and Landsburg). This could be accomplished by measuring *in situ* groundwater flow at three cross section along each aquifer flow channel in the following manner:

- Select and secure access to each flow cross section such that it includes an existing water well that can be used for test pumping;
- Perform geophysical surveys using electromagnetic resistivity methods along each cross section to identify and map depth to bedrock;
- Install a monitoring well 20 to 75 feet upstream and downstream of each water well to log and sample aquifer materials, confirm geophysical interpretations, measure groundwater levels, observe drawdowns, and determine the hydraulic gradient; and
- Perform a 24-hour constant-rate pumping test, including monitored recovery, in each of the water wells to create drawdown data in the monitoring wells from which aquifer permeability and estimates of the distance to lateral hydraulic boundaries can be determined.

With this information, Darcy's law can be applied to calculate the amount of groundwater flowing through each cross section. Performing this field test on three cross sections in each aquifer flow channel will provide greater accuracy,

but will be more costly than testing just one cross section in each channel. There will still be some element of uncertainty associated with the flow measurements but this can be quantified through an error analysis of the field data.

### 7.2.4 Stress Periods

The accuracy and flexibility of the transient model may be hampered by the use of a monthly stress periods. The additional work on recharge rates (see above) and Clark Springs withdrawal and augmentation rates (see below) could provide sufficient data to warrant transient groundwater flow modeling with shorter stress periods of between 5 and 10 days.

### 7.2.5 Model Duration

Detailed stream augmentation flow data and Clark Springs withdrawal data should be extracted from the City's telemetry system for the last 5-year period since 1998 to enable more accurate simulation runs covering the last 5-year period during which streamflow augmentation has been implemented by the City.

### 7.2.6 Model Layering

For the BA, we relied upon published data and previous studies that have characterized the lithology of the outwash aquifer. Geologic data from water wells and other available well logs should be analyzed to see whether there is sufficient data and geologic variation to justify establishing a three-layer model within ModFlow, especially within the Rock Creek aquifer channel. To facilitate this work, the Clark Springs Facility could be represented using a more detailed multi-layered submodel.

### 7.2.7 Baseflow Discharge

The drainage package was the preferred method for simulating the occurrence of baseflow discharge to Rock Creek within the Clark Springs Watershed. The use of drain cells should be expanded upstream in Rock Creek to Lake No. 12, and should include Georgetown Creek to simulate baseflow discharge with higher groundwater levels that are likely to be seen with a weekly time step. Additional field survey data would be required to get accurate elevation data along both creeks.

### 7.2.8 Clark Springs Hydrogeology

The modeling has demonstrated that the hydrogeology at Clark Springs is not straight-forward, and may be difficult to represent with the required level of accuracy in a model of this type without further substantial refinements. These may include:

- Using a modified form of the stream-routing package in place of drain cells.
- Varying aquifer properties and layering in the model to better simulate short-term stress tests that involve changes in water withdrawal or augmentation.
- Examining the effect of geometry assumptions about the depth and width of permeable material forming the aquifer channel.

The simulations of the 2001 system test suggest that revisiting these issues in more detail could enable improved representation and accuracy of the model results in this critical area, especially if supported by the following field studies.

### 7.2.9 Field Studies

A better understanding of the hydrogeologic behavior at Clark Springs is needed to better quantify differences in the stream-aquifer hydraulics that strongly affect the performance and modeling of withdrawals via the gallery, and streamflow augmentation from the clear well.

- Install nested piezometers adjacent to the creek, upstream and downstream of the infiltration gallery at Clark Springs, between the clear well and the flume, and between the flume and the Kent Kangley road bridge;
- Install and calibrate staff gages in Rock Creek at the same locations as the piezometers; and
- Perform a series of at least three week-long monitoring tests at different flow levels in Rock Creek, monitoring the piezometers and streamflows while variably operating the Clark Springs withdrawal facilities and augmentation pumps.

Detailed field performance monitoring of this level is necessary to take the modeling work a stage further and enable more rigorous examination of the

complex interrelationship that exists between the groundwater and streamflow in this critical area.

## 8.0 SUMMARY AND CONCLUSIONS

The groundwater model of the Rock Creek catchment presented in this report is reflective of our current understanding of the catchment and has accomplished our objectives stated in Section 1.1. This model adequately simulates regional groundwater levels on a steady-state basis and more importantly, simulates the transient groundwater/surface water interaction in the vicinity of the Clark Springs Watershed.

The construction and calibration phases of this model effort have brought forth important characteristics of the basin not previously known and/or understood.

- The relationship between the upper catchment and flow in the intermediate aquifer channels is complex; however, based upon previous investigations and our conceptual model, the response time for flow between the upper catchment and the aquifer channels is relatively quick and direct.

- Hydraulic conductivity (K) and specific yield (Sy) are integral parameters in the groundwater model, yet based upon current model construction (aquifer depth and K distribution) their individual effect on the model is relatively limited, confirming that the critical model-defining parameter is groundwater recharge.

- Timing, distribution, and amount of recharge occurring in the upper catchment significantly impact the catchment's hydrology. Specific yield does provide a dampening effect, but the overall transmissive nature of the aquifer promotes a very responsive groundwater system that stores infiltrating water and transmits a portion of it readily to Clark Springs and Rock Creek.

- Significant drawdown effects from groundwater extraction at the Clark Springs Facility (infiltration gallery or pumping wells) do not propagate beyond the eastern end of the Rock Creek Channel due to the high gradients and shallow aquifer base upstream of Clark Springs. Withdrawals produced some local drawdown effect at the western end; however, the

shallow depth of the Rock Creek aquifer channel appears to prevent the drawdown response from propagating further upstream.

- The response time between the infiltration gallery and the Rock Creek stream channel is very fast when compared to other documented groundwater/surface water interaction studies.

- The amount of baseflow capture due to the operations of Clark Springs Facility causes some loss in streamflow, but the effect is reduced at low-flow conditions.

As described in Section 7.0, this model is not without limitations; however, based on current available data and our conceptual model, we feel this model provides enhanced understanding of the groundwater hydrology of the Rock Creek catchment, and allows the general effects of water system withdrawals to be simulated. Additionally, we feel this model will aid the City in its current work on the Habitat Conservation Plan and for addressing future groundwater management issues.

## 9.0 REFERENCES


Anderson, M. P. and W. W. Woessner 1992. Applied Groundwater Modeling: San Diego, CA: Academic Press.

Brown & Caldwell 1980. Cedar River Well Field Study, Phase II; Final Report prepared for Seattle Water Department, March 15, 1980.

Domenico, P. A. and F.W. Schwartz 1990. Physical and Chemical Hydrogeology: New York, NY: John Wiley and Sons.

Ecology 2003. WRIA 9 Duwamish/Green Map Themes: Township/Range/ Sections. Washington State Department of Ecology Internet Website URL: http://www.ecy.wa.gov/services/gis/maps/wria/townships/trs9a.pdf

GeoEngineers 2000. A Hydrology Evaluation for the Boundary Line Adjustment, Ravensdale, Washington, prepared for the Jack McCann Company.

Hart Crowser 1996. Wellhead Protection Program for the City of Kent and their Clark, Kent, and Armstrong Spring Facilities.

King County 1987. Draft Environmental Impact Statement, Kangley Site Sand and Gravel Operation, Proposed Rezone. May 1987.

Kresic, N. 1997. Quantitative Solutions in Hydrogeology and Groundwater Modeling: New York, NY: Lewis Publishers.

McDonald, M. and A. Harbaugh 1998. ModFlow, A Three-Dimensional Finite-Difference Ground-Water Flow model. USGS Open File Report 83-875.

Robertson, F., and Anderson, K.E. 1957. Geology and Ground Water Resources in Glacial Stream Channel of Rock Creek. Report prepared for City of Kent.

Robinson and Noble, Inc. 1995. Wellhead Protection Plan for the Covington Water District.

Waterloo Hydrogeologic 2000. Visual ModFlow for Windows, version 2.8.2. January 2000.

F:\docs\jobs\747005\ModFlow Report.doc

## Table 1 - User Defined MODFLOW Solution Parameters

| | Steady-State Solution | Transient Solution |
|---|---|---|
| Maximum Number of Outer Iterations | 600 | 600 |
| Maximum Number of Inner Iterations | 75 | 75 |
| Preconditioning Method | MIC | MIC |
| Head Change Criterion for Convergence | 0.25 | 0.75 |
| Residual Criterion for Convergence | 100 | 100 |
| Printout Interval | 10 | 10 |
| Number of Stress Periods | n/a | 24 |
| Number of Time Steps per Stress Period | n/a | 40 |
| Time Step Multiplier | n/a | 1.2 |

* MIC = Modified Incomplete Cholesky method

## Table 2 - Long-Term Groundwater Recharge Values Derived from HSPF for the 1944 to 1998 Period of Record

| ModFlow Property ID | Rock Creek Sub Basin ID | Recharge Rate in in/yr |
|---|---|---|
| 1 | #1 | 31.0 |
| 2 | R1 | 37.4 |
| 3 | R2 | 35.3 |
| 4 | Ravensdale | 50.0 |
| 5 | R3A | 56.5 |
| 6 | R3F | 47.1 |
| 7 | R7A | 53.4 |
| 8 | none | 0.0 |
| 9 | R3D | 34.4 |
| 10 | R6 | 32.3 |
| 11 | R5C | 35.1 |
| 12 | R9B | 53.5 |
| 13 | R4A | 35.1 |
| 14 | R4B | 49.3 |
| 15 | R3B | 34.3 |
| 16 | R5A | 33.4 |
| 17 | R5B | 50.7 |
| 18 | R5D | 35.3 |
| 19 | R9A | 38.7 |
| 20 | #20 | 44.0 |
| 21 | #21 | 42.0 |

Note:
Rock Creek Sub-basin IDs correspond with HSPF modeling work except for numbered sub-basin outside of the HSPF model domain.

## Table 3 - Water Balance for Steady-State Simulation

| Groundwater Inflows in cfs | |
|---|---|
| CONSTANT HEAD | 0.3 |
| WELLS | 0.0 |
| DRAINS | 0.0 |
| RECHARGE | 33.0 |
| Total Inflows: | 33.3 |
| **Groundwater Outflows in cfs** | |
| CONSTANT HEAD | 24.9 |
| WELLS | 4.0 |
| DRAINS | 4.8 |
| RECHARGE | 0.0 |
| Total Outflows | 33.6 |
| Inflows - Outflows | -0.4 |
| PERCENT DISCREPANCY | -1.13 |

Note:

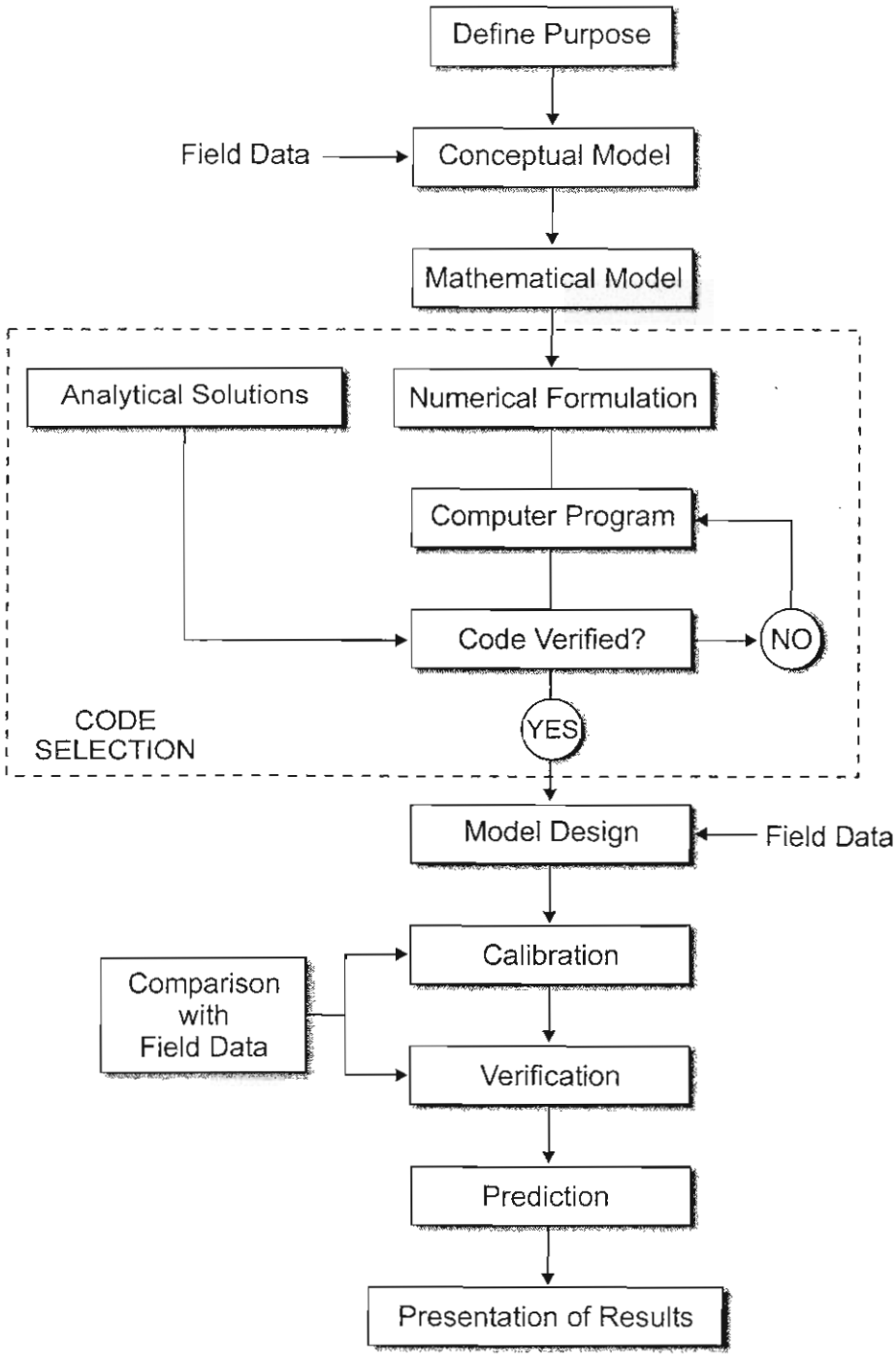
CONSTANT HEAD - represent flows to and from the downgradient aquifer and the Cedar River
WELLS - represent flows from the infiltration gallery
DRAINS - represent groundwater discharge to Rock Creek

Table 4 - Water Balance and Groundwater Flow Distribution for Transient Simulation

| Water Year 1998: | October | November | December | January | February | March | April | May | June | July | August | September | Averages |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Flow in cfs | | | | | | | |
| **Modeled Flows** | | | | | | | | | | | | | |
| Groundwater Entering Rock Creek Aquifer Channel | 13.8 | 13.9 | 14.0 | 14.8 | 14.4 | 14.7 | 13.7 | 12.9 | 12.4 | 11.6 | 10.9 | 10.3 | 13.1 |
| Percentage of total | 48.0% | 48.1% | 48.2% | 49.0% | 48.9% | 49.4% | 48.2% | 47.4% | 46.8% | 45.8% | 45.0% | 44.2% | 47.4% |
| Groundwater Exiting Rock Creek Aquifer Channel | 4.2 | 4.4 | 4.7 | 4.5 | 4.1 | 3.3 | 3.6 | 4.0 | 3.4 | 3.7 | 3.3 | 3.6 | 3.9 |
| Groundwater Entering Ravensdale Aquifer Channel | 12.8 | 12.9 | 13.0 | 13.3 | 13.0 | 13.0 | 12.7 | 12.4 | 12.1 | 11.8 | 11.4 | 11.1 | 12.5 |
| Percentage of total | 44.7% | 44.8% | 44.8% | 44.2% | 44.2% | 43.8% | 44.8% | 45.4% | 45.8% | 46.6% | 47.2% | 47.8% | 45.3% |
| Groundwater Entering Landsburg Aquifer Channel | 2.1 | 2.0 | 2.0 | 2.1 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 1.9 | 1.9 | 1.8 | 2.0 |
| Percentage of total | 7.2% | 7.1% | 7.0% | 6.8% | 6.9% | 6.8% | 7.1% | 7.3% | 7.4% | 7.6% | 7.8% | 7.9% | 7.2% |
| Infiltration Gallery Flows (Model Input) | 5.8 | 5.5 | 4.9 | 5.7 | 6.2 | 8.0 | 6.8 | 5.8 | 6.6 | 5.6 | 6.0 | 5.2 | 6.0 |
| Groundwater Discharging to Rock Creek (Drain Cells) | 4.1 | 4.2 | 4.6 | 5.1 | 4.5 | 4.2 | 3.5 | 3.3 | 2.7 | 2.3 | 1.8 | 1.5 | 3.5 |
| Measured Flow at Clark Springs Flume * | 4.0 | 5.7 | 7.6 | 16.6 | 13.9 | 12.3 | 9.5 | 6.0 | 5.2 | 4.2 | 3.3 | 3.2 | 7.6 |
| **Water Balance** | | | | | | | | | | | | | |
| Flow into the Model | 52.0076 | 48.5485 | 53.2436 | 72.7983 | 50.4743 | 56.6519 | 46.2203 | 43.7678 | 41.8652 | 37.8237 | 35.7818 | 33.3626 | n/a |
| Flow out of the Model | 52.0070 | 48.5485 | 53.2438 | 72.7987 | 50.4746 | 56.6515 | 46.2202 | 43.7681 | 41.8651 | 37.8238 | 35.7820 | 33.3631 | n/a |
| Percentage Discrepency | 1.02E-03 | -2.77E-05 | -3.95E-04 | -5.05E-04 | -6.30E-04 | 6.33E-04 | 1.55E-04 | -5.94E-04 | 2.14E-04 | -1.30E-04 | -5.32E-04 | -1.72E-03 | n/a |

* Includes surface runoff not represented in ModFlow

## *Groundwater Modeling Approach*
### *Adapted from Anderson & Woessner (1992)*



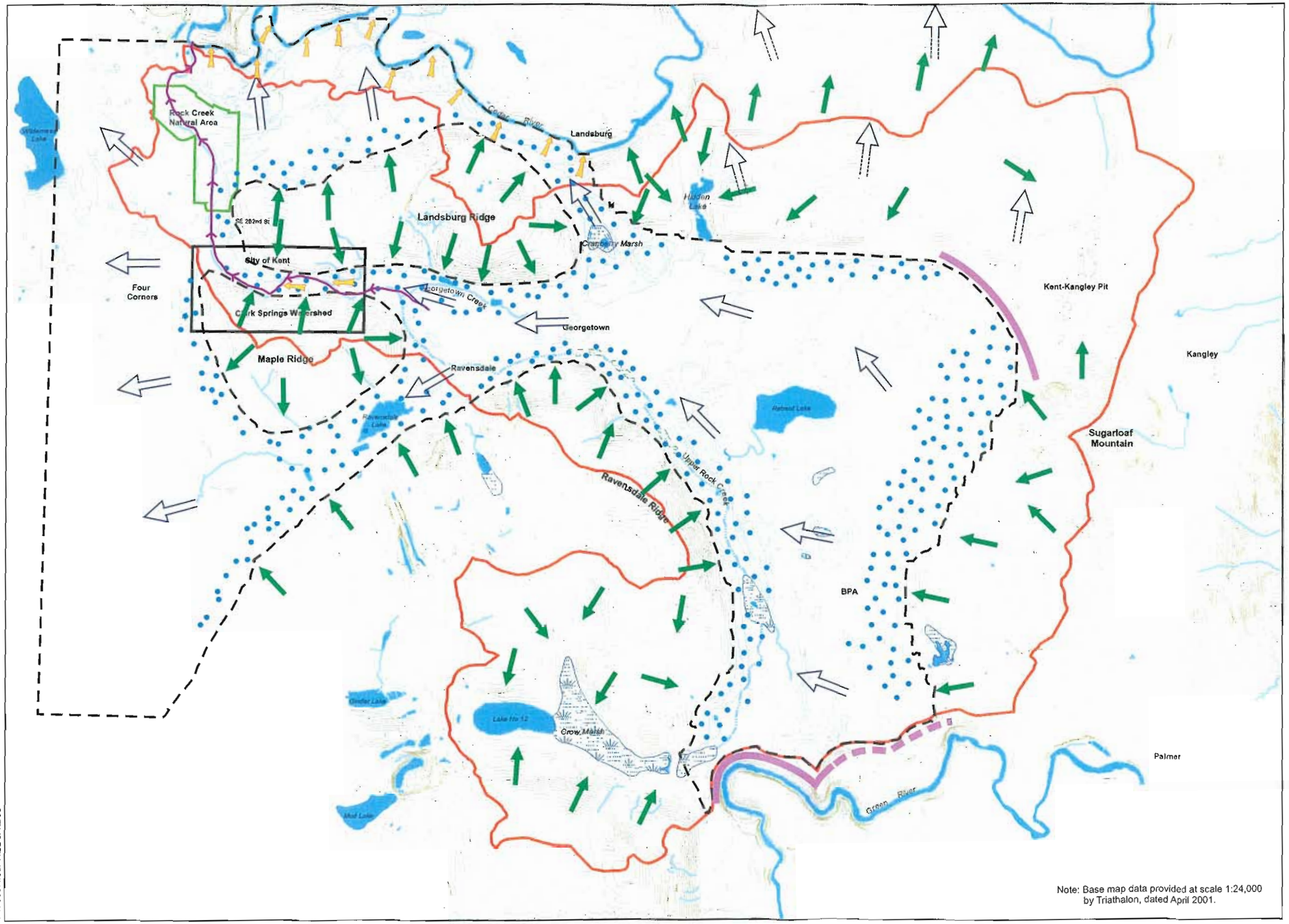

747005a.cdr DNK 8/9/02

HARTCROWSER

*7470-05* *3/03*

*Figure 1*

## *Conceptual Schematic for HSPF and ModFlow Modeling Tasks*
### *Rock Creek Catchment*




Note: Base map data provided at scale 1:24,000 by Triathalon, dated April 2001.

- Modeled Aquifer Extent (ModFlow)
- Rock Creek Catchment (HSPF)
- Clark Springs Watershed
- Rock Creek Natural Area Boundary
- Perennial Stream
- Intermittent Stream
- Surface Water Body
- Wetland (Undelineated)
- Wetland (Delineated by King County)
- Surface Elevation Contour Line
- Runoff and Interflow from Till-Covered Hills
- Bedrock Barriers to Subsurface Flow
- Groundwater Flow in Outwash Aquifer (Dashed if Outside Model)
- Baseflow Discharge
- Enhanced Recharge from Hillside Runoff/Interflow
- Perennial Surface Water Flow
- Limits of Groundwater Flow Domain Modeled in ModFlow

N

0 3000 6000

Approximate Scale in Feet

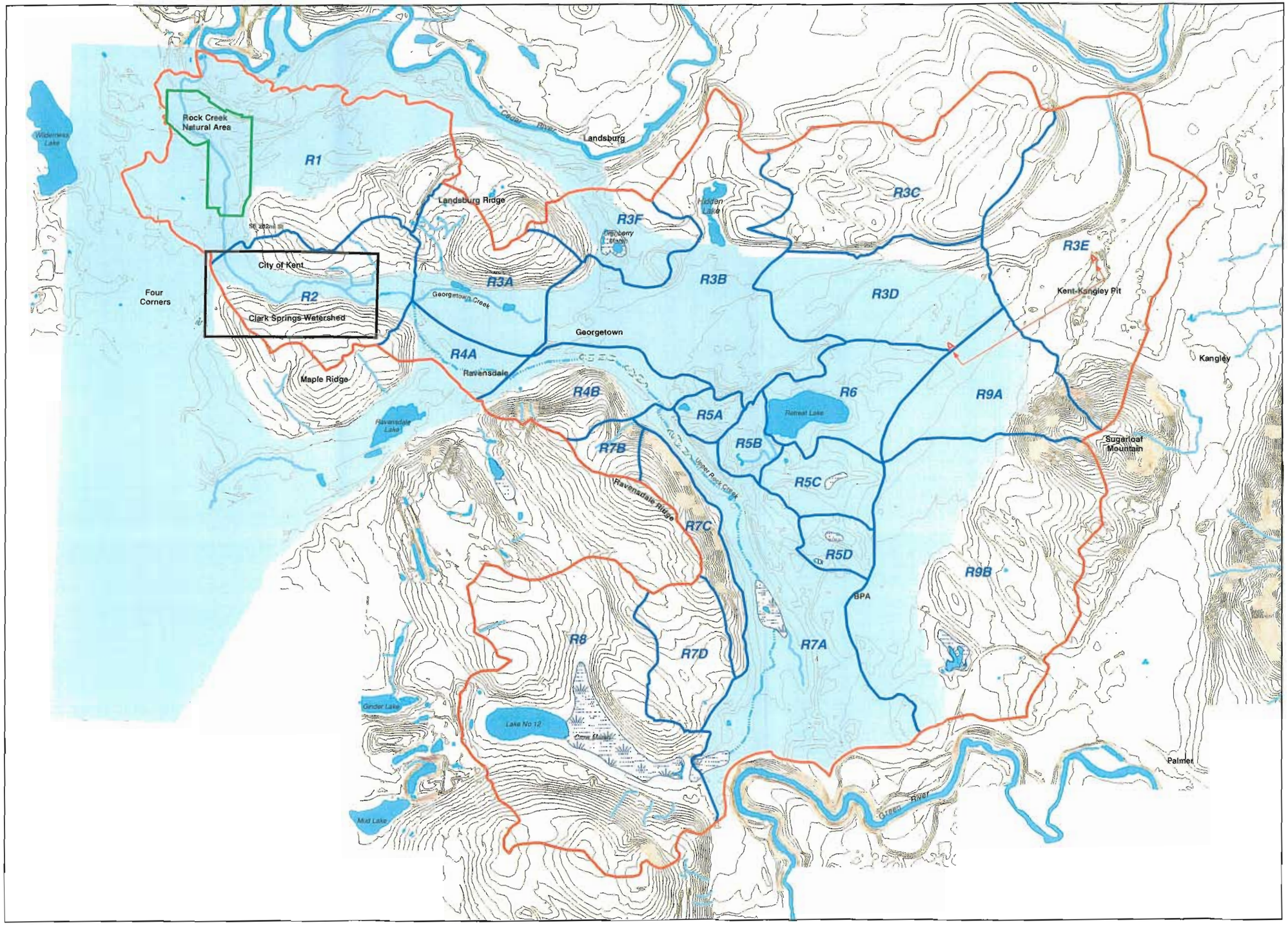
HARTCROWSER

*7470-05* *3/03*

***Figure 2***

747005N.cdr HEL 3/12/03

## *Modeled Aquifer Extent and Recharge Sub-Basins*
### *Rock Creek Basin*




**Legend**

- Modeled Aquifer Extent
- Rock Creek Basin
- R3A — Sub-basin Boundary and Number
- Clark Springs Watershed
- Rock Creek Natural Area Boundary
- Perennial Stream
- Intermittent Stream
- Surface Water Body
- Wetland (Undelineated)
- Wetland (Delineated by King County)
- Surface Elevation Contour Line
- A A' Approximate Location of Cross Section in Figure 4

N

0 1,500 3,000 6,000

Scale in Feet
Scale = 1:36,000

Notes:

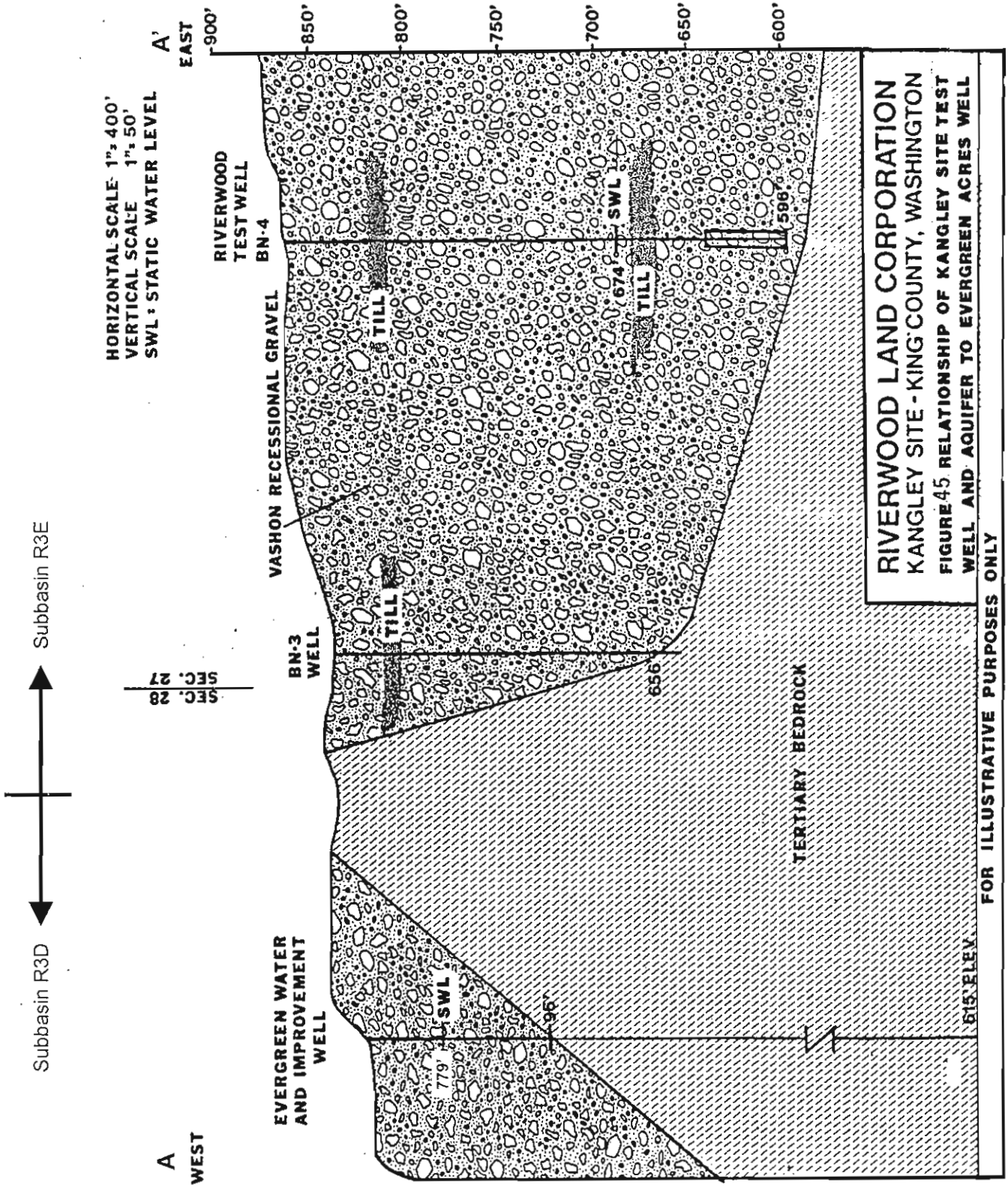
1) Base map data provided by Triathalon at scale 1:24,000 dated April 2001.

HARTCROWSER

*7470-05* *3/03*
*Figure 3*

JOBS\7470\Report Figs\Fig_3.mxd cog 3/12/03

## Bedrock Barrier Between Subbasins R3D and R3E




747005AA.CDR DNK 2/24/03

*Source:* Kangley Site Sand and Gravel Operation Proposed Rezone, King County Dept. Of Planning and Community Development, Figure 45, Relationship of Kangley Site Test Well and Aquifer to Evergreen Acres Well, May, 1987. (See Figure 3 for approximate location of cross section).

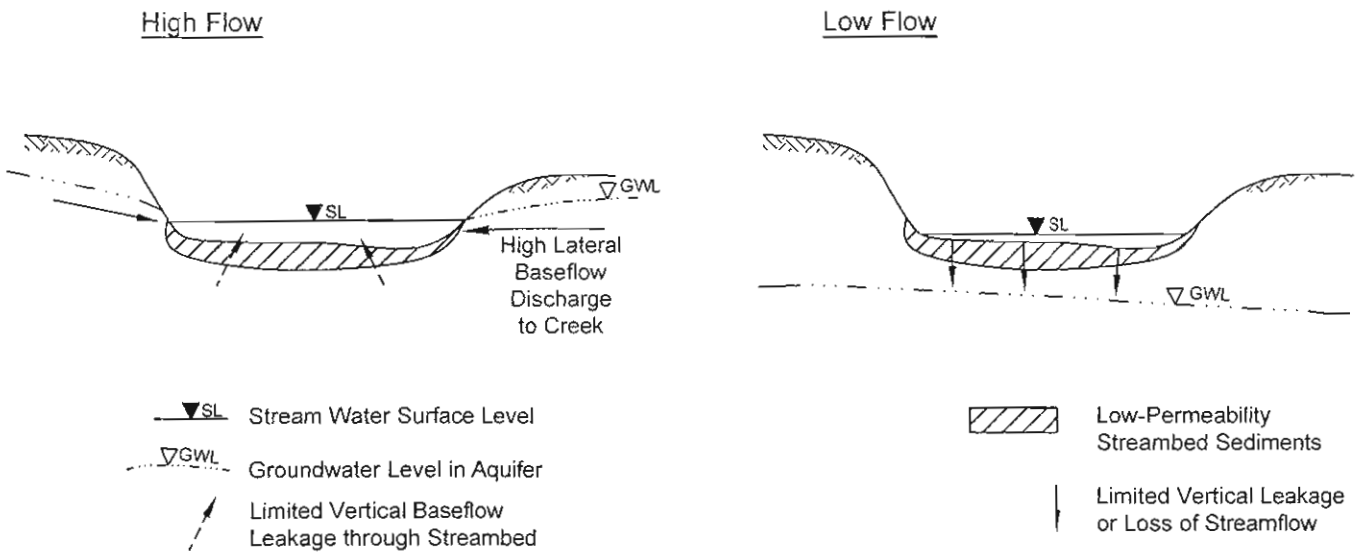
HARTCROWSER

*7470-05* *3/03*

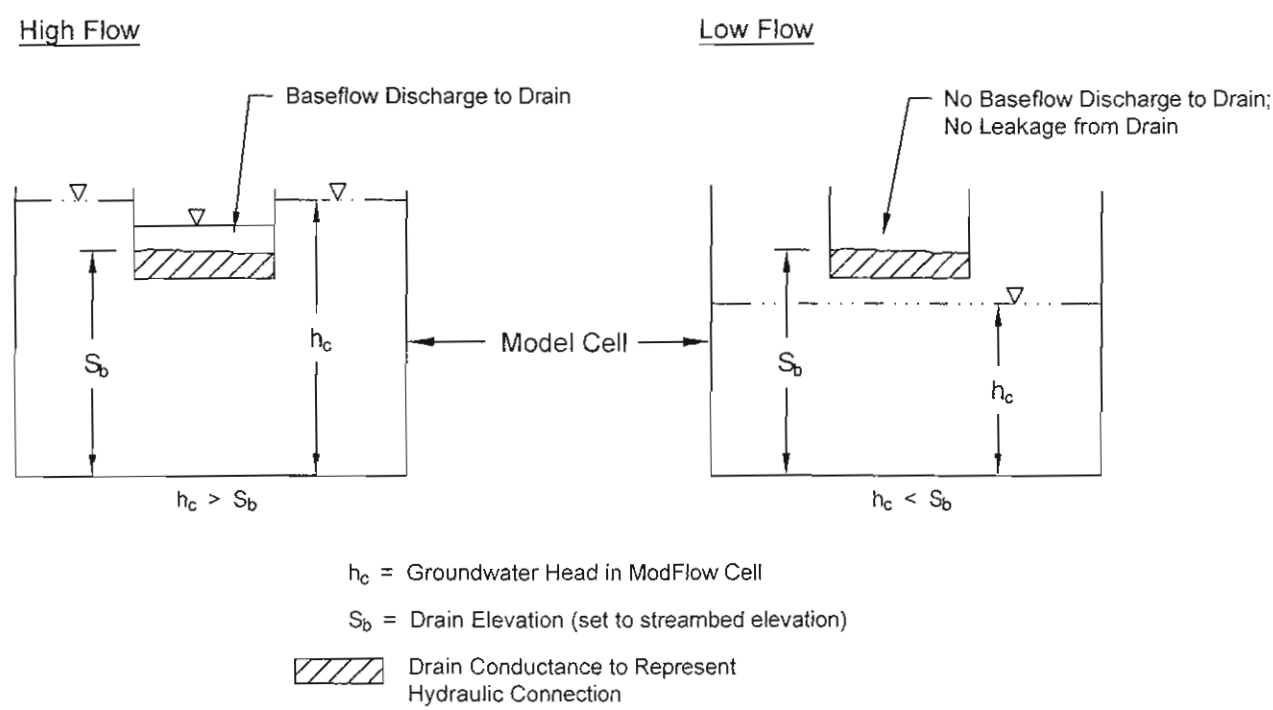
*Figure 4*

# Modeling Stream - Aquifer Interaction with the Drain Package

## A) Conceptual Model for Rock Creek at Clark Springs




## B) Representation in ModFlow using the Drain Package



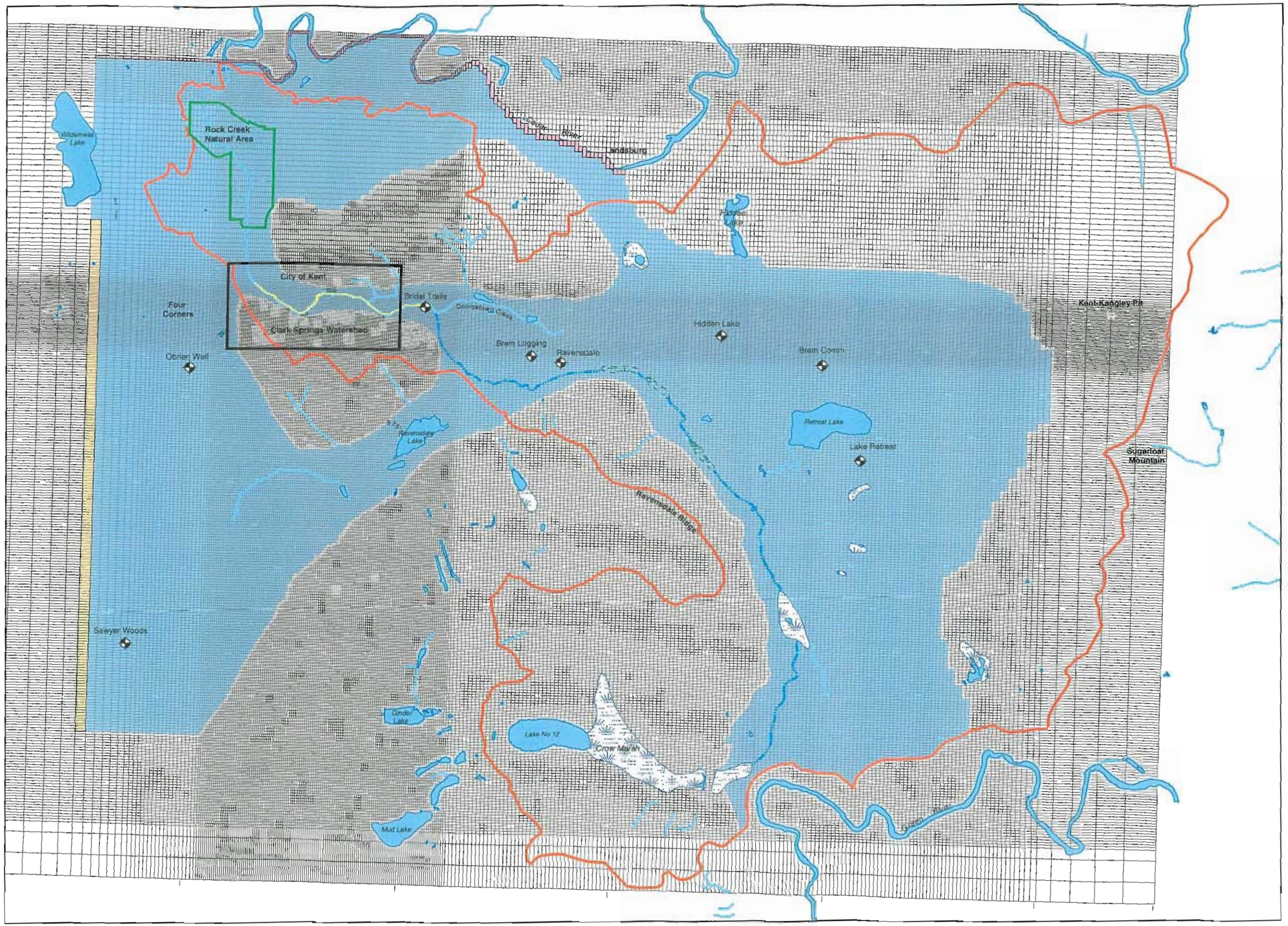

747005002.dwg HEL 2/26/03

HARTCROWSER

7470-05 3/03

Figure 5

## *Model Grid and Boundary Conditions*
### *Rock Creek Basin*




F:\DATA\GIS\JOBS\7470\REPORT FIGS\Fig_6.mxd cog 03/12/03

**Legend**

- Modeled Aquifer Extent
- Downgrade Aquifer Constant Heads
- Cedar River Constant Heads
- Drain Cells
- Grid Cells
- Rock Creek Basin
- Perennial Stream
- Intermittent Stream
- Rock Creek Natural Area Boundary
- Clark Springs Watershed
- Surface Water Body
- Wetland (Undelineated)
- Wetland (Delineated by King County)
- Bridal Trails — WHPA Calibration Target Well (Location and Name)

N

0 1,500 3,000 6,000

Scale in Feet

Scale = 1:36,000

Note:

1) Base Map data provided by Triathlon at scale 1:24,000 dated April 2001

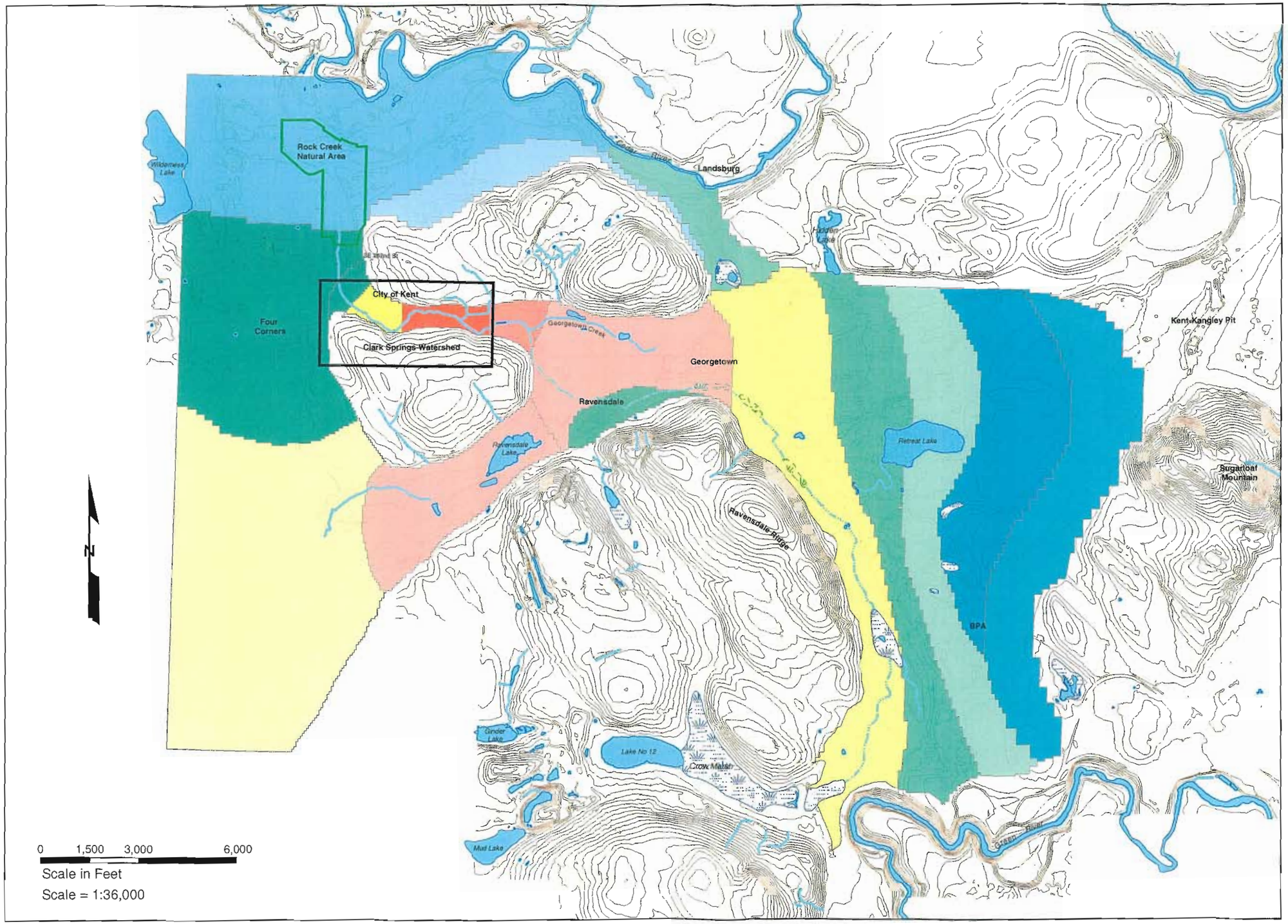
HARTCROWSER

*7470-05* *3/03*

*Figure 6*

## *Hydraulic Conductivity Distribution (From Calibrated Model)*

### *Rock Creek Basin*




**Legend**

- Perennial Stream
- Intermittent Stream
- Elevation Contour in Feet
- Surface Water Body
- Wetland (Undelineated)
- Wetland (Delineated by King County)
- Rock Creek Natural Area Boundary
- Clark Springs Watershed

**Hydraulic Conductivity in ft/day**

- 3
- 11
- 17
- 28
- 57
- 85
- 113
- 142
- 283
- 425
- 850
- 2268
- 2835
- 5669
- 8504

Notes:

1) Base map data provided by Triathalon at scale 1:24,000 dated April 2001.

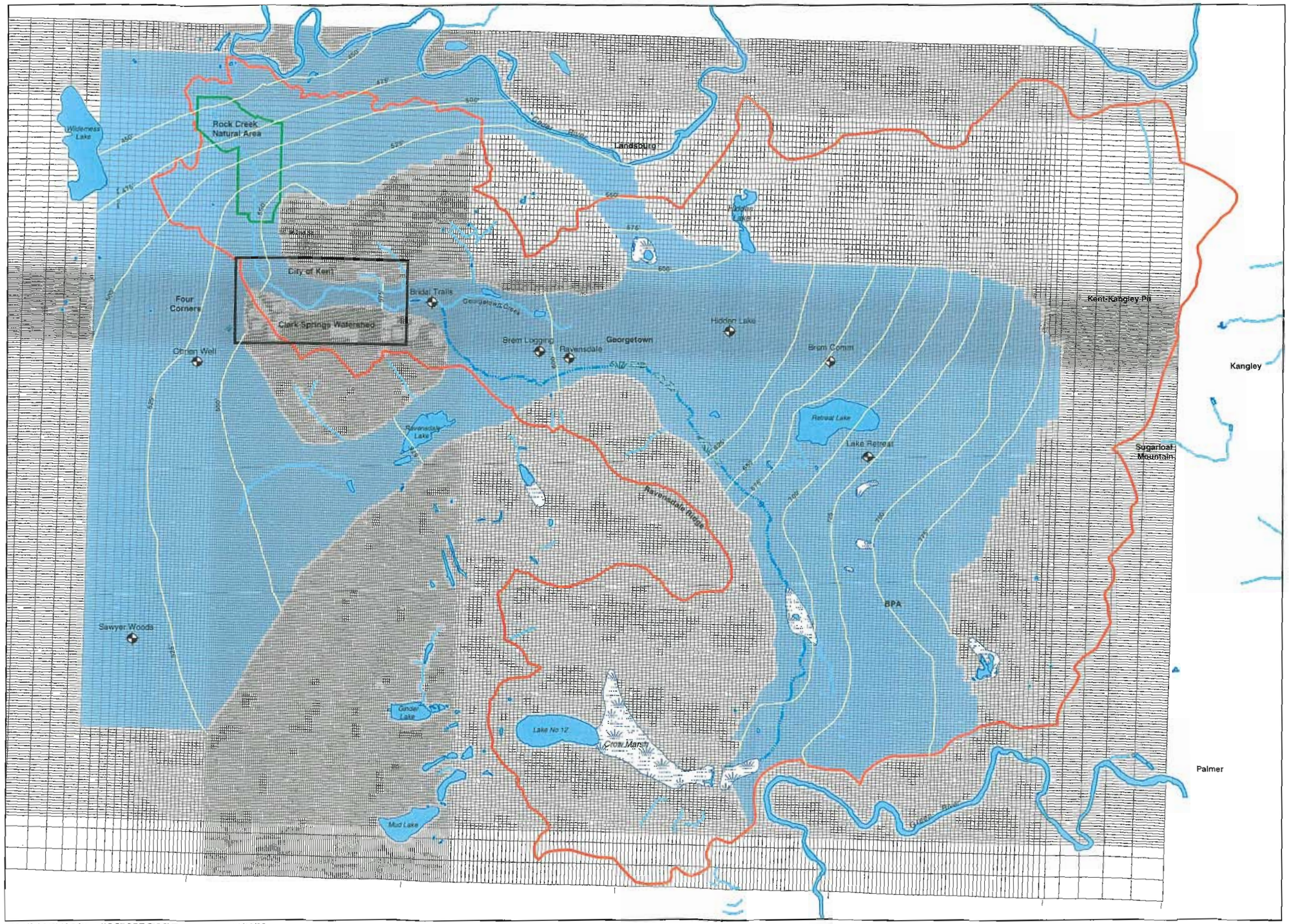
HARTCROWSER

*7470-05* *3/03*

*Figure 7*

F:\DATA\GIS\JOBS\7470\REPORT FIGS\Fig_7.mxd 3/12/03

## *Robinson and Noble Generalized Water Table Elevation Contour Map*
### *Rock Creek Basin*




F:\DATA\GIS\JOBS\7470\REPORT FIGS\Fig_8.mxd cog 03/12/03

**Legend**

- Modeled Aquifer Extent
- Rock Creek Natural Area Boundary
- Clark Springs Watershed
- Grid Cells
- Rock Creek Basin
- 600' Water Table Elevation Contour in Feet
- Perennial Stream
- Intermittent Stream
- Surface Water Body
- Wetland (Undelineated)
- Wetland (Delineated by King County)
- Bridal Trails — WHPA Calibration Target Well (Location and Name)

N

0 1,500 3,000 6,000

Scale in Feet

Scale = 1:36,000

Notes:

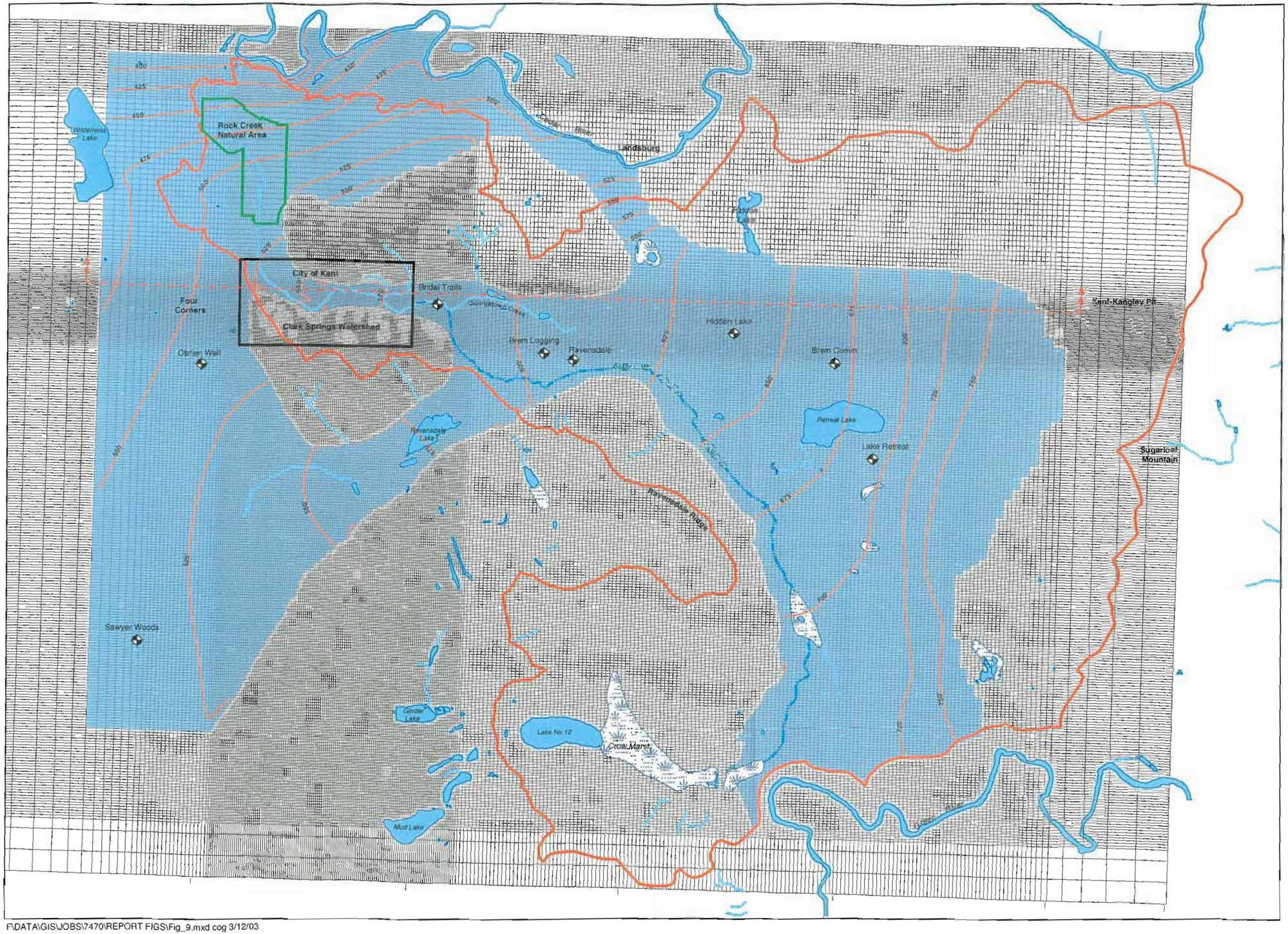
1) Base Map data provided by Triathlon at scale 1:24,000 dated April 2001

HARTCROWSER

*7470-05* *3/03*

***Figure 8***

## *Simulated Steady-State Water Table Elevation Contour Map*
### *Rock Creek Basin*




## Legend

- Modeled Aquifer Extent
- Grid Cells
- 500' Water Table Elevation Contour in Feet
- Rock Creek Basin
- Perennial Stream
- Intermittent Stream
- Rock Creek Natural Area Boundary
- Clark Springs Watershed
- Surface Water Body
- Wetland (Undelineated)
- Wetland (Delineated by King County)
- Bridal Trails WHPA Calibration Target Well (Location and Name)
- A A' Model Cross Section Shown in Figure 10

N

0 1,500 3,000 6,000

Scale in Feet

Scale = 1:36,000

Note:

1) Base Map data provided by Triathlon at scale 1:24,000 dated April 2001

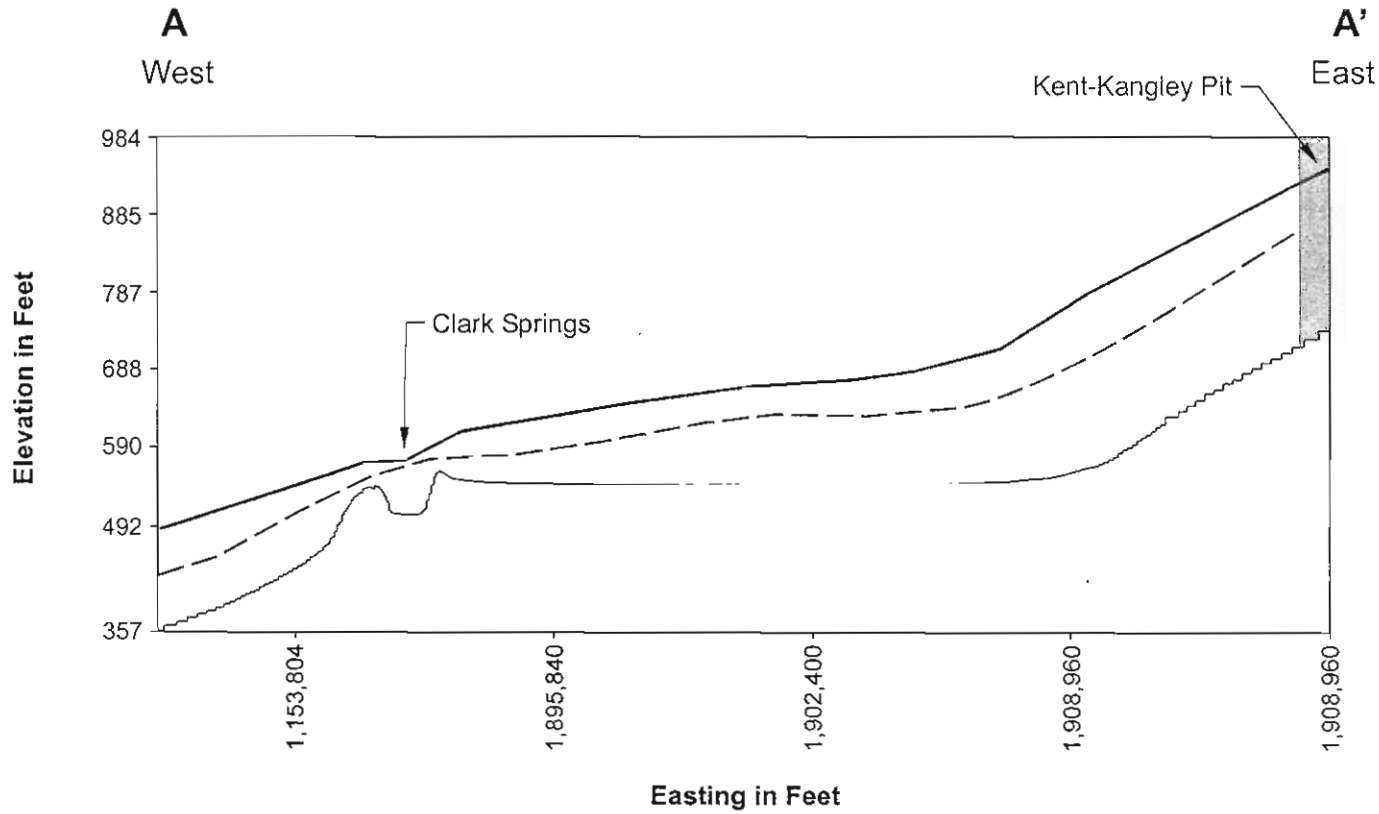
HARTCROWSER

*7470-05* *3/03*

*Figure 9*

F:\DATA\GIS\JOBS\7470\REPORT FIGS\Fig_9.mxd cog 3/12/03

## *Typical Model Cross Section Showing Aquifer Thickness*




(Vertical Exaggeration x20)

Ground Surface

Groundwater Level

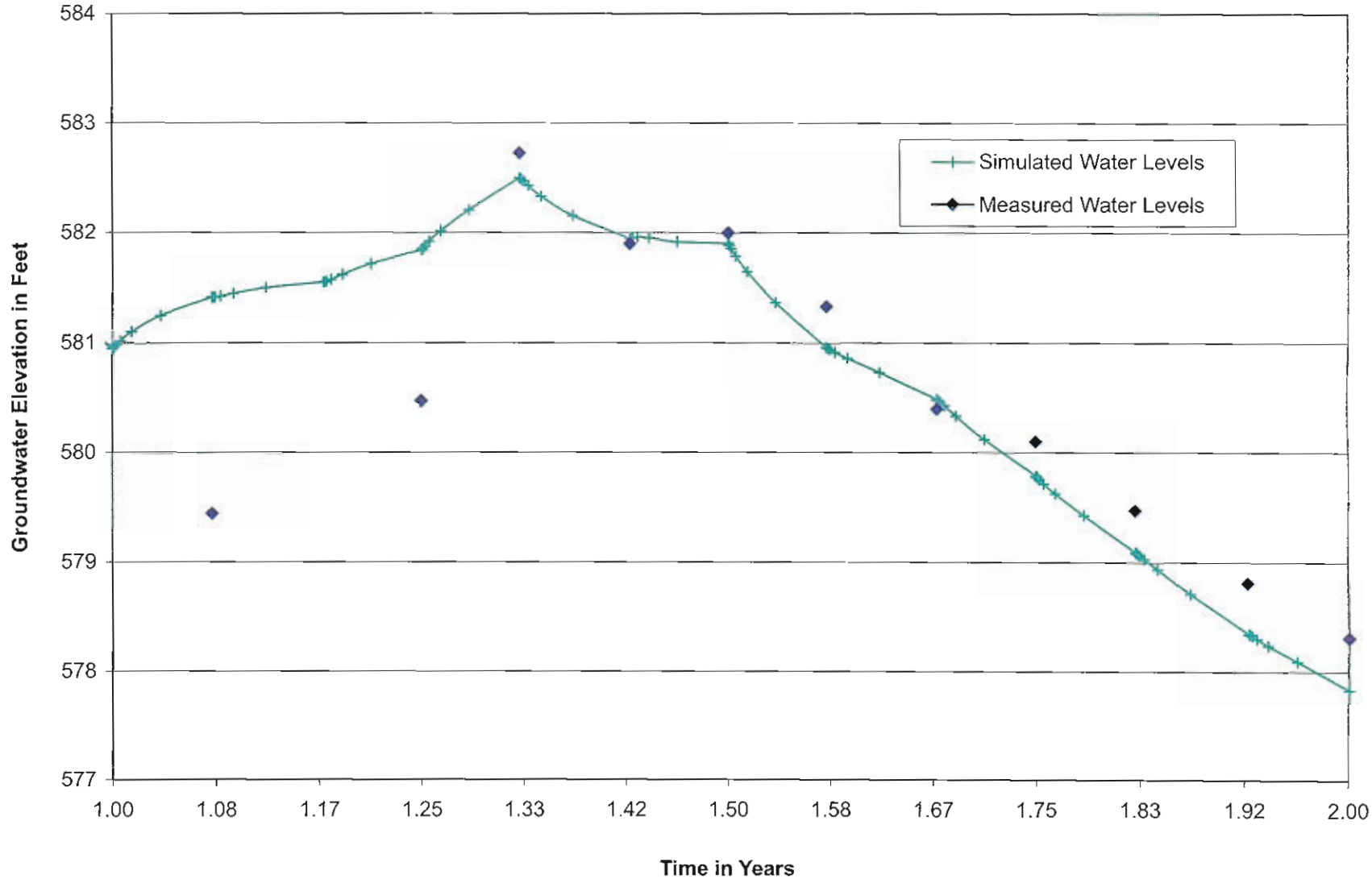
Base of Model (Bedrock Surface)

Note: See Figure 9 for location of cross section.

HARTCROWSER
7470-05
Figure 10
3/03

747005m.cdr DNK 3/10/03

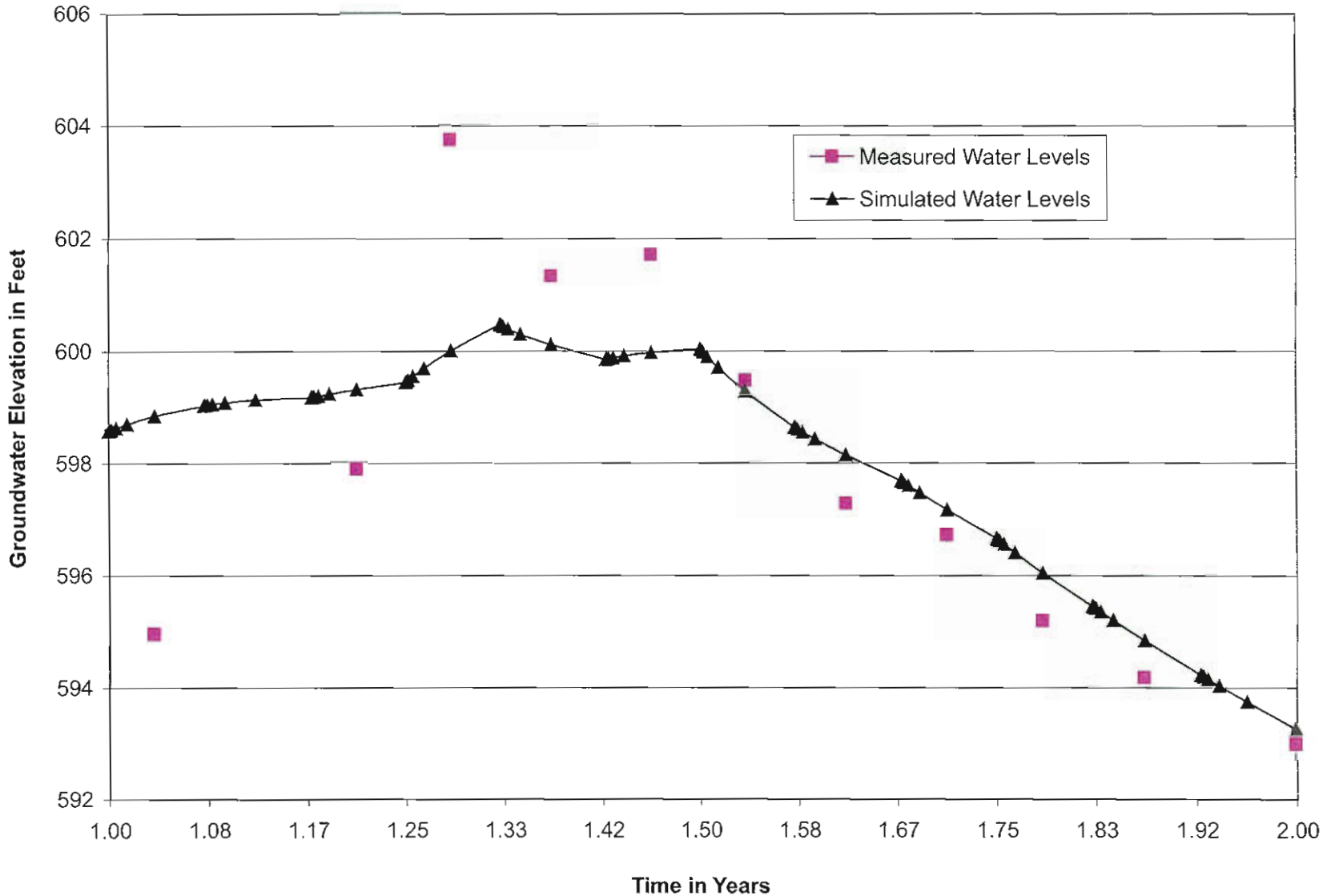
## *Transient Water Level Calibration for the 1998 Water Year*
### *Bridle Trails Well*




HARTCROWSER
7470-05
Figure 11
3/03

747005B.cdr DNK 3/10/03

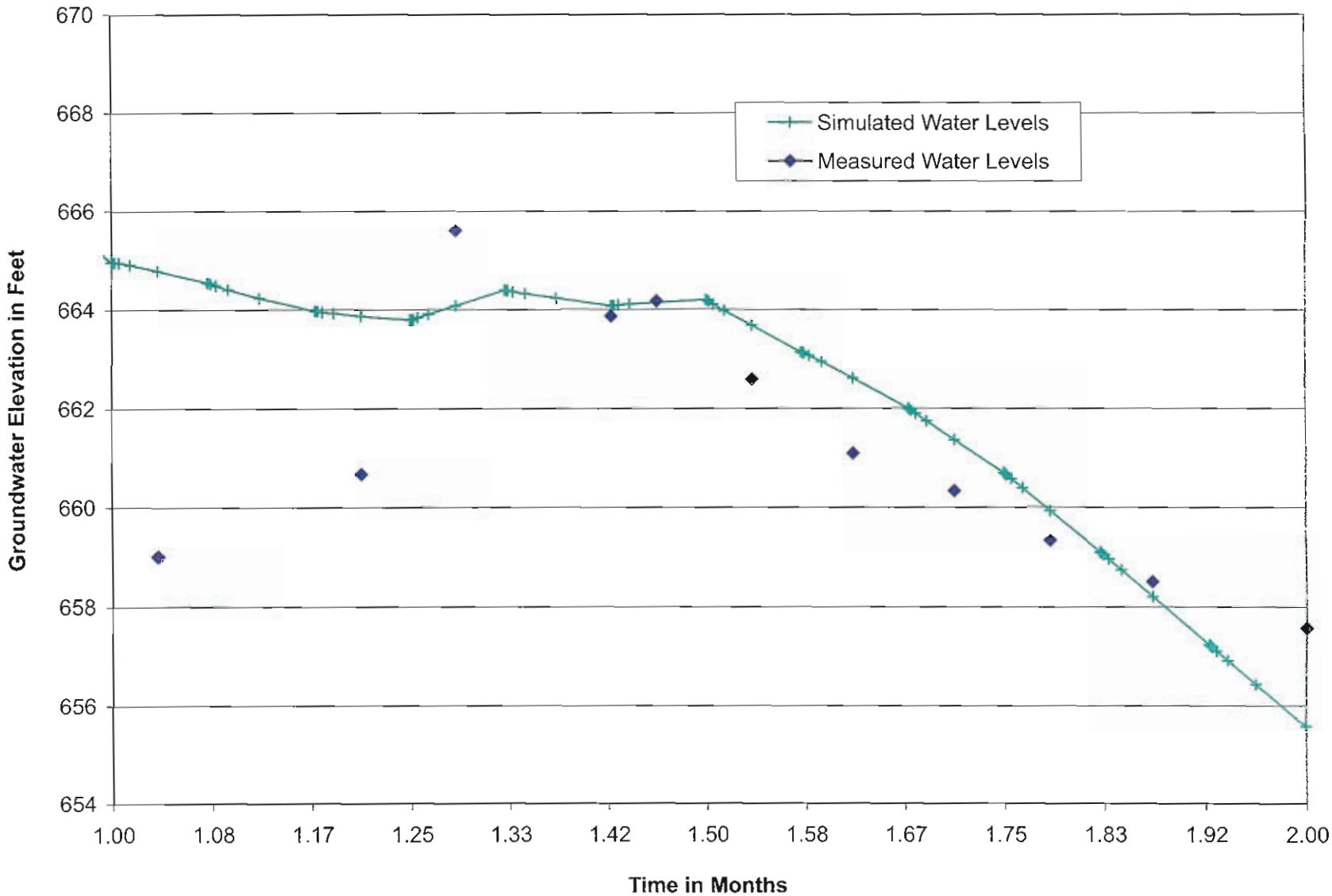
## *Transient Water Level Calibration for the 1998 Water Year*
### *Bremmeyer Logging Well*




HARTCROWSER
7470-05
3/03
Figure 12

747005C.cdr DNK 3/10/03

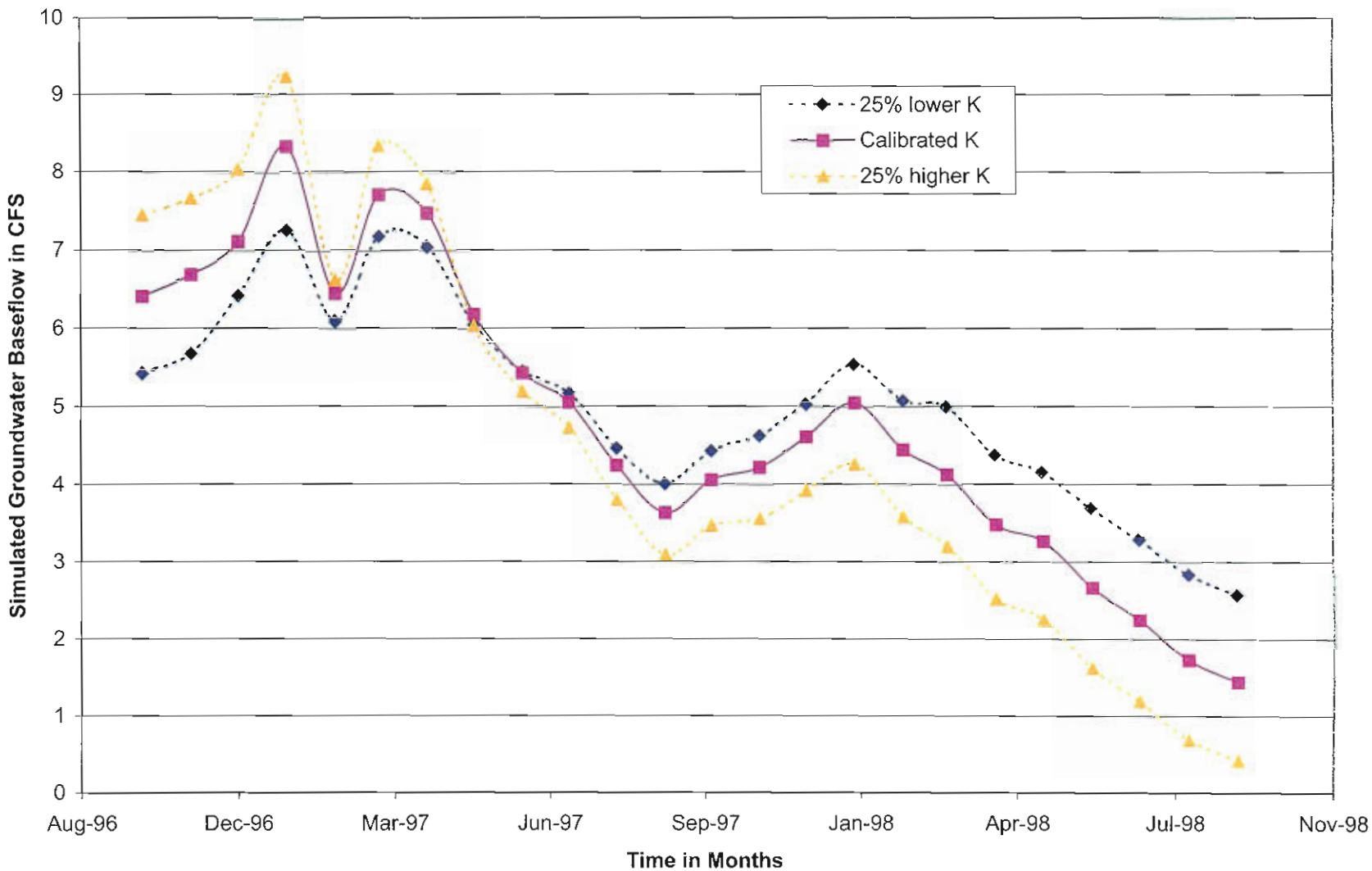
## *Transient Water Level Calibration for the 1998 Water Year*
### *Bremmeyer Community Well*




HARTCROWSER
7470-05
Figure 13
3/03

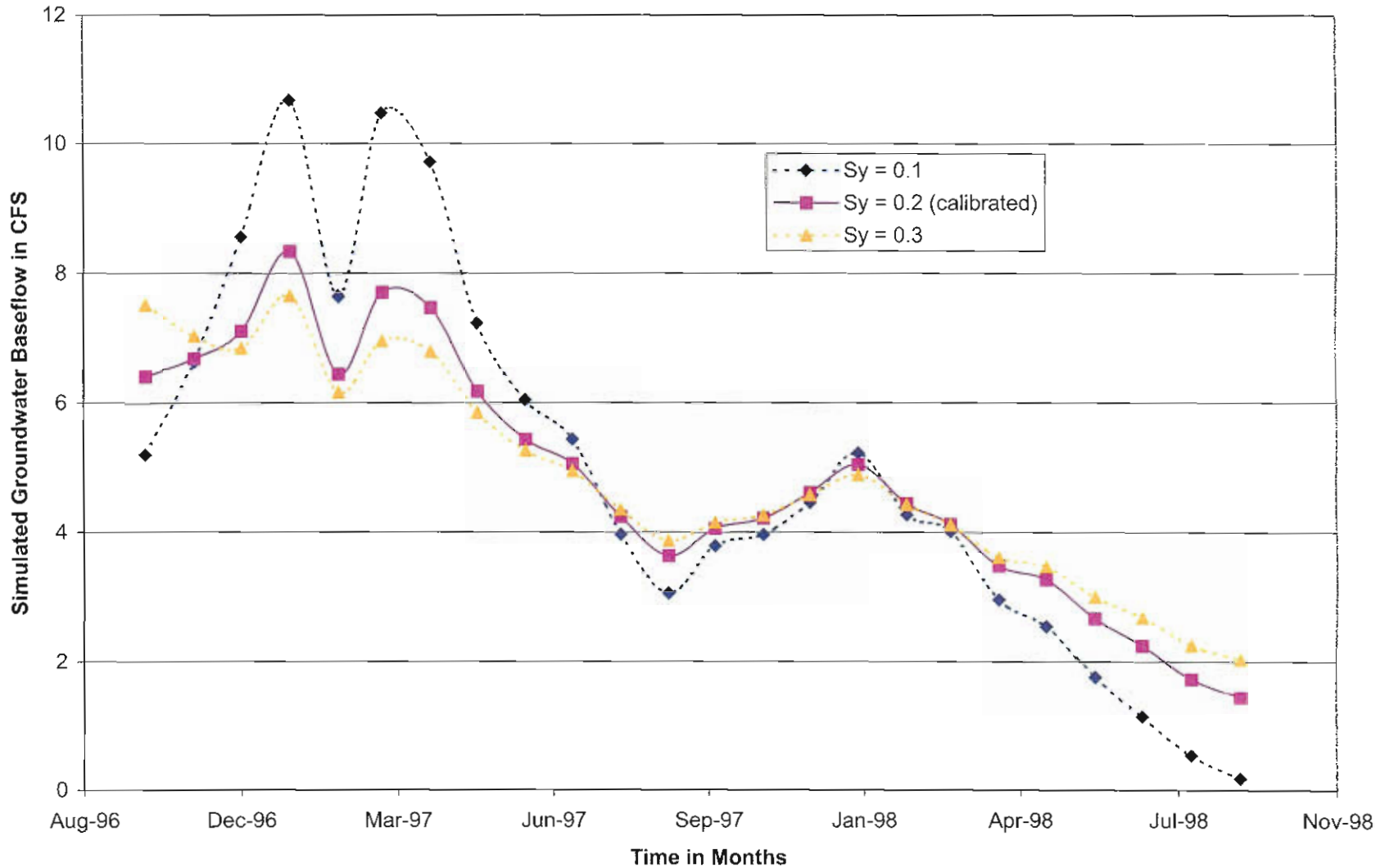
747005D.cdr DNK 8/9/02

## *Sensitivity Analysis*
### *Hydraulic Conductivity Effects on Rock Creek Baseflow*




HARTCROWSER
7470-05
3/03
Figure 14

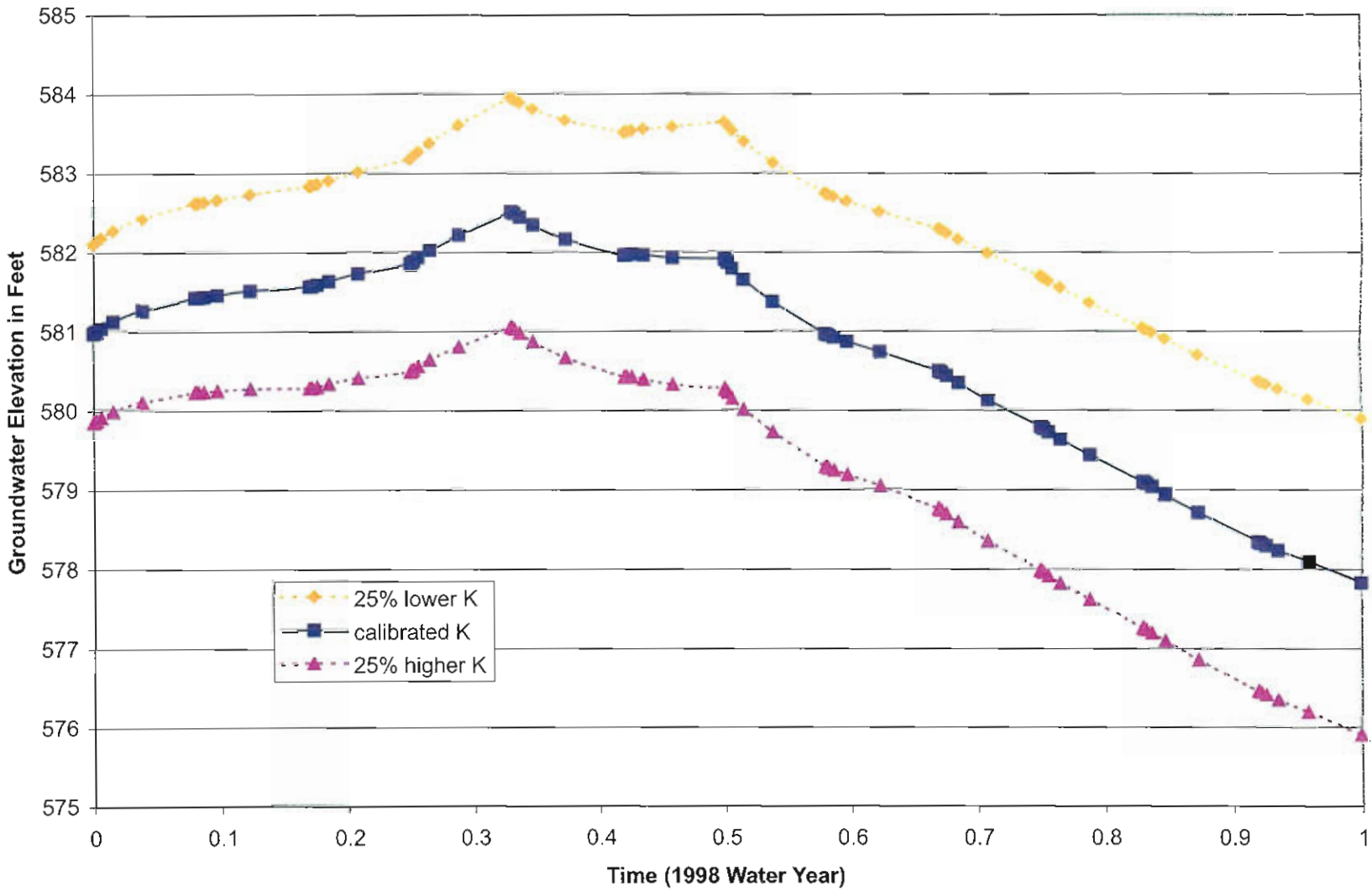
## *Sensitivity Analysis*
### *Specific Yield Effects on Rock Creek Baseflow*




HARTCROWSER
7470-05
Figure 15
3/03

747005H.cdr HEL 8/9/02

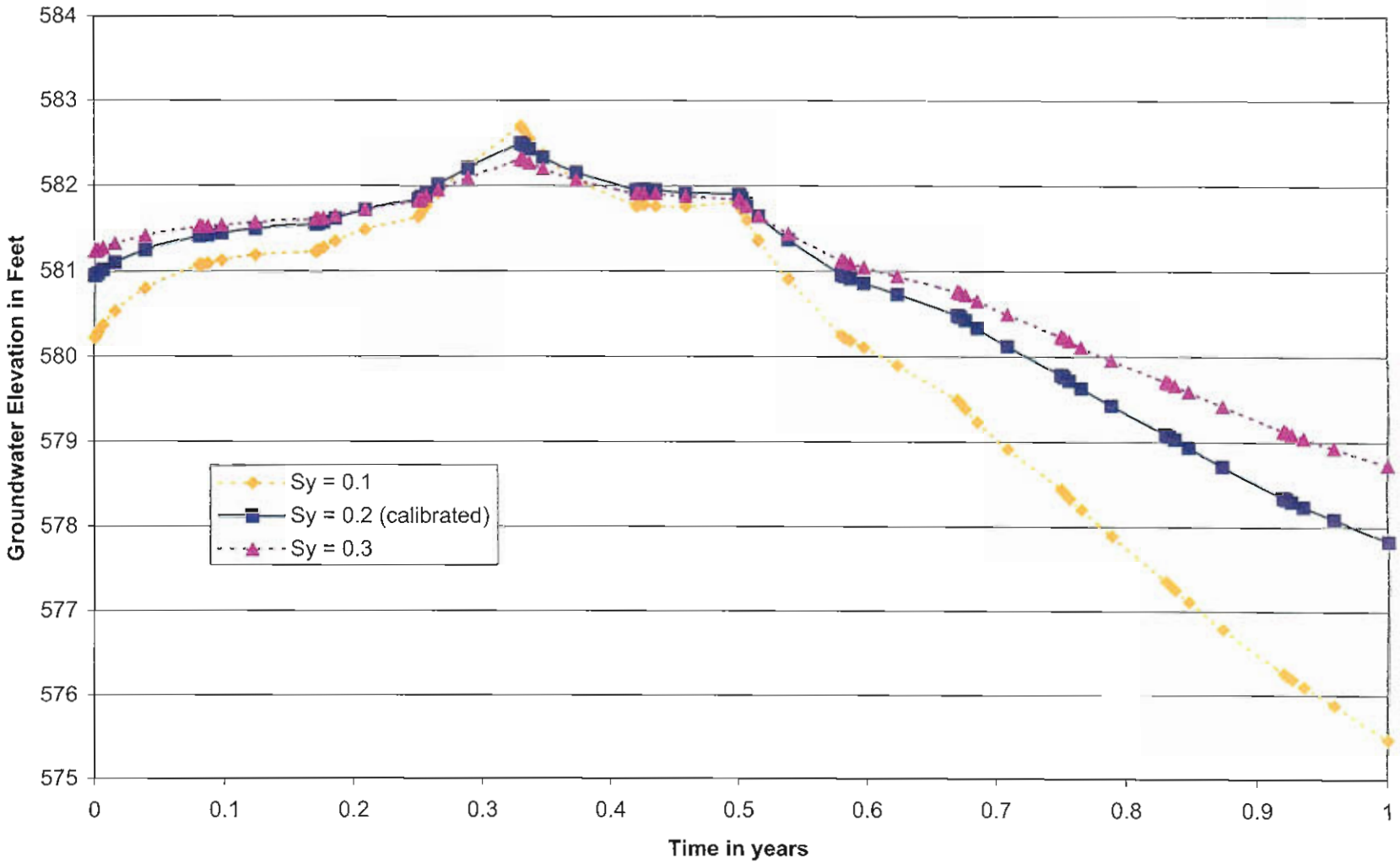
## *Sensitivity Analysis*
### *Hydraulic Conductivity Effects on Groundwater Levels - Bridle Trails Well*




HARTCROWSER
7470-05
Figure 16
3/03

747005K.cdr DNK 8/9/02

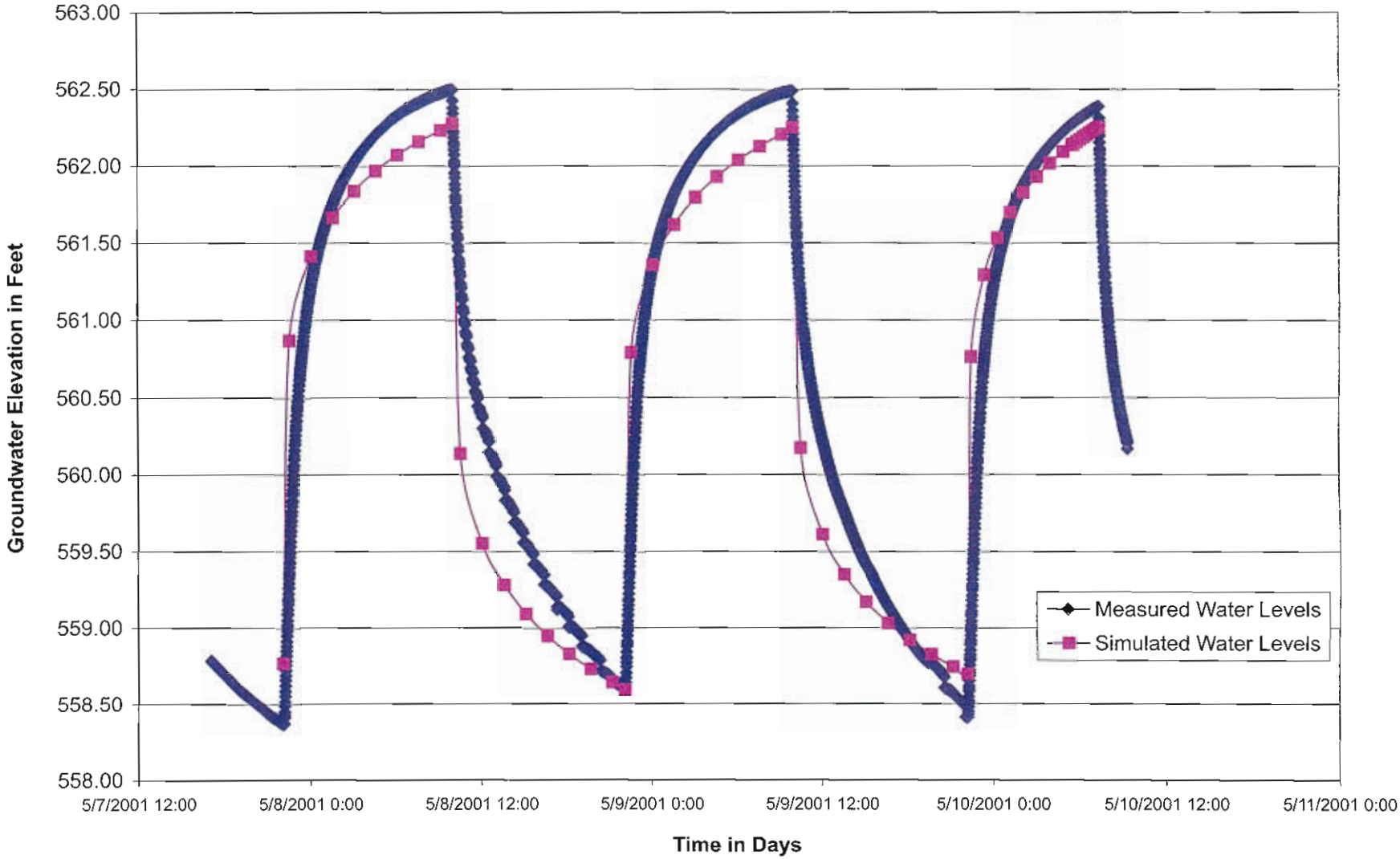
## *Sensitivity Analysis*
### *Specific Yield Effects on Groundwater Levels - Bridle Trails Well*




HARTCROWSER
7470-05
Figure 17
3/03

747005J.cdr DNK 8/9/02

## *Simulated and Measured Water Levels for the May 2001 System Test*




HARTCROWSER
7470-05
3/03
Figure 18

747005G.cdr DNK 8/9/02

*This page intentionally left blank.*

# APPENDIX E

## HSPF Model Calibration Report – City of Kent Clark Springs Water Supply Operations in the Rock Creek Catchment

*This page intentionally left blank.*

# HSPF Model Calibration Report
# City of Kent Clark Springs Water Supply Operations in the Rock Creek Catchment

**Prepared for:**

**City of Kent Department of Public Works**

**by**

MGS Engineering Consultants, Inc.

7326 Boston Harbor Road NE
Olympia, WA 98506
(360) 570-3450

**March 31, 2005**

# HSPF Model Calibration Report
# City of Kent Clark Springs Water Supply Operations in the Rock Creek Catchment

**MGS Engineering Consultants, Inc.**
**7326 Boston Harbor Road NE**
**Olympia, Washington 98506**
**(360) 570-3450**

The engineering analyses and technical material presented in this report were prepared under the supervision and direction of the undersigned professional engineer.

Bruce Barker, P.E.

## EXECUTIVE SUMMARY

Analyses were conducted using the HSPF[1] hydrologic model to examine and characterize the hydrology of the Rock Creek watershed and the effects of water supply withdrawals at the City of Kent's, Clark Springs Water Supply System. This report summarizes the development of the HSPF model, documents the final model configuration and presents the results of the model calibration.

The HSPF model used in the study was originally developed by King County as part of the Cedar River Basin Plan[2]. As part of the current study, the model was refined and updated several times as streamflow and augmentation data became available, and as the understanding of the relationship between the surface and groundwater flow in the vicinity of Clark Springs developed.

Calibration is the process whereby model input parameters are adjusted until simulated and recorded streamflow match to the greatest extent possible. Three time periods were used in the HSPF model calibration and represent a wide range of climatic and water withdrawal conditions;

1. Water Years 1955-1965
2. Water Years 1986-1998
3. February 2002 – February 2003

Model calibration results show close agreement between simulated and recorded streamflow for the more than 32-years of data used in the calibration indicating that the model accurately simulates Rock Creek streamflow for a variety of climatic, withdrawal, and streamflow augmentation conditions. Simulated low flow discharge rates (less than 6 cfs) were typically within 5% of recorded under natural conditions with low withdrawal rates from Clark Springs and within 8% of recorded under current conditions, which included streamflow augmentation. Thus, the model is valid as a tool for examining the effects of water withdrawal and augmentation scenarios on streamflow. Results of various water supply withdrawal and augmentation simulation scenarios will be presented in a subsequent report.

## TABLE OF CONTENTS

**INTRODUCTION** ..... 1
**HSPF MODEL APPLICATION TO THE ROCK CREEK CATCHMENT** ..... 2
*Relationship Between HSPF and MODFLOW Groundwater Model* ..... 2
*Subbasin Definitions* ..... 3
*Geology* ..... 5
*Land Cover* ..... 5
*Stream Definition/ Channel Routing* ..... 6
*Development of Precipitation Timeseries for Hydrologic Analyses* ..... 6
*HSPF Model Representation of the Clark Springs Water Supply System* ..... 9
*HSPF Model Schematic* ..... 10
**HSPF MODEL CALIBRATION** ..... 12
*Calibration Periods/Data Availability* ..... 12
*Model Simulation of Clark Springs Pump Test* ..... 13
*HSPF Model Calibration Approach* ..... 15
*Initial HSPF Model Calibration Results Water Years 1955-1965* ..... 15
*HSPF Model Calibration Results Water Years 1966-1973* ..... 18
*Initial HSPF Model Calibration Results Water Years 1985-1998* ..... 20
*HSPF Model Validation Results February 2002-February 2003* ..... 22
**FINAL HSPF MODEL CALIBRATION RESULTS** ..... 24
**CONCLUSIONS** ..... 31
**REFERENCES** ..... 32

# Rock Creek HSPF Model Calibration Report
# City of Kent Clark Springs Water Supply Operations in the Rock Creek Catchment

## INTRODUCTION

The US EPA Hydrological Simulation Program Fortran[1] (HSPF) is a conceptual, continuous, hydrologic model where surface, shallow subsurface (interflow), and groundwater flows can be simulated, lagged, and combined as discharge into a stream network. In application, the watershed to be modeled is divided into a number of subbasins that are connected by channel reaches. Subbasin delineations include information on land cover and geologic/soil type and are based on topography, hydrologic characteristics, the channel network, and locations where computed streamflows are desired. The principal inputs to the model are hourly precipitation and evaporation timeseries and the primary model output is decades long, continuous, hourly timeseries of streamflows at each subbasin outlet that can be used to analyze Rock Creek streamflow and Clark Springs Water Supply System (CSWSS) operations.

The analysis was performed to help the City assess aquatic habitat related to the operation of the CSWSS. The HSPF model used in this study was developed and refined over several years as streamflow and augmentation data became available, and as the understanding of the relationship between the surface and groundwater flow in the vicinity of Clark Springs developed. Preliminary model configurations and calibration results are presented in the reports: *Hydrologic Analysis of the City of Kent Clark Springs Water Supply Operations in the Rock Creek Catchment Using the HSPF Model*[3] and *Hydrologic Analysis of City of Kent Clark Springs Water Supply Operations in the Rock Creek Catchment Using the HSPF Model – Supplemental Analyses*[4]. The model configuration and calibration results presented in this report supersede the results presented in the previous reports cited above.

Recently, streamflow data used in previous model calibration efforts for the 1986-1998 period were found to be over-estimated by up to 2.5 cfs due to backwater effects at the Clark Springs flume. The data were corrected and the HSPF model recalibrated. This report summarizes the relevant findings of the pervious reports, documents the final model configuration, and presents the results of the model calibration.

## HSPF MODEL APPLICATION TO THE ROCK CREEK CATCHMENT

### *Relationship Between HSPF and MODFLOW Groundwater Model*

Surface water (HSPF) and groundwater (MODFLOW[5]) models were developed to analyze the hydrology of the Rock Creek watershed. Development and calibration of these models was achieved using an interactive process whereby information developed from each model was incorporated into the other (Figure 1). This approach allowed each model to take advantage of the strengths of the other.

First, recharge to the aquifer computed using HSPF was used as input to the MODFLOW model. Second, groundwater elevations simulated with MODFLOW were compared to water levels recorded at wells throughout the study area and model parameters adjusted until simulated and recorded levels matched. Next, groundwater flow paths and amounts traveling through the watershed identified in the MODFLOW model were used in HSPF and the HSPF model parameters were adjusted until simulated and recorded streamflow data matched. Estimates of groundwater recharge were then recomputed using HSPF and the process was repeated until close agreement between the modeled and recorded streamflows and groundwater levels was achieved. MODFLOW model development and calibration is documented in the report, *Rock Creek Catchment Groundwater Flow Model*, May 2003[6].

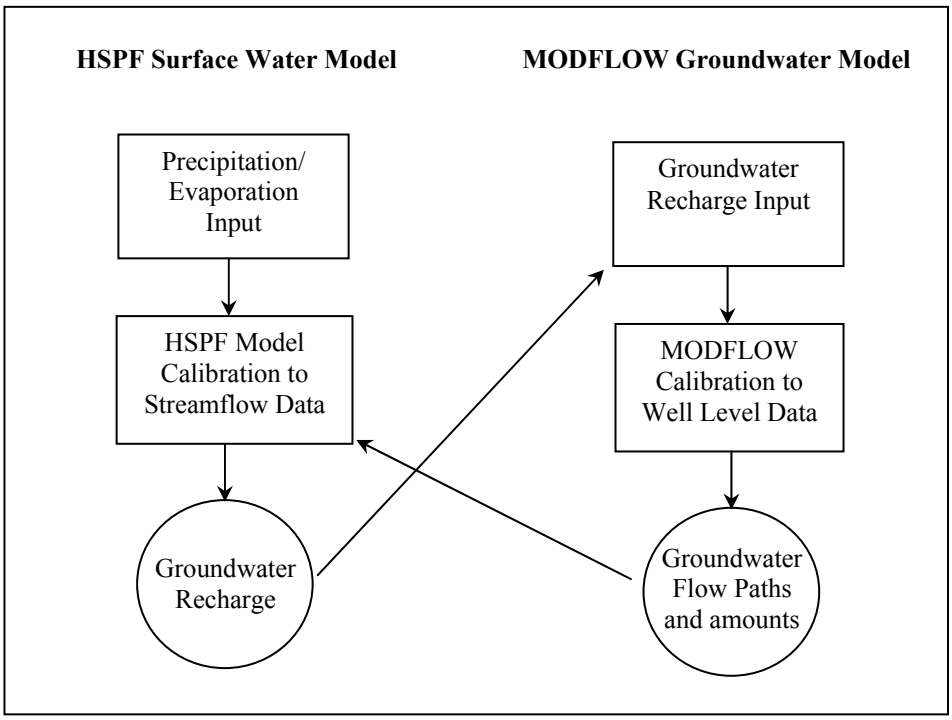



**Figure 1 – Schematic of HSPF Surface Water and MODFLOW Groundwater Model Interactive Calibration Process**

***Subbasin Definitions***

For purposes of hydrologic analysis, the Rock Creek watershed was partitioned as shown in Figure 2. A previous analysis of the watershed was performed by King County Department of Public Works using the HSPF model as part of the Cedar River Basin Plan[2]. That model was adopted and refined for use in this study. The nine subbasins used in the King County analysis were subdivided to provide a better spatial representation of the precipitation inputs and groundwater discharges in the watershed and to provide correspondence with the MODFLOW aquifer boundary. This resulted in delineation of 22 subbasins for the HSPF analysis presented here. A detailed topographic survey prepared for the City of Kent by Triathalon was used to define the watershed and subbasin boundaries, which provides a more accurate representation of the watershed than was available previously.

The area within each subbasin was classified into areas of common land cover and geologic/soil type called *PERLNDS* (short for pervious land segments). The total surface area belonging to each PERLND type within each subbasin was computed using land use, geology, and topographic overlays in a GIS. The HSPF model computes the hydrologic response of each PERLND within a subbasin on a per-unit-area basis and proportions the amount of surface runoff, interflow, and groundwater entering the stream of each subbasin consistent with the computed PERLND area totals.

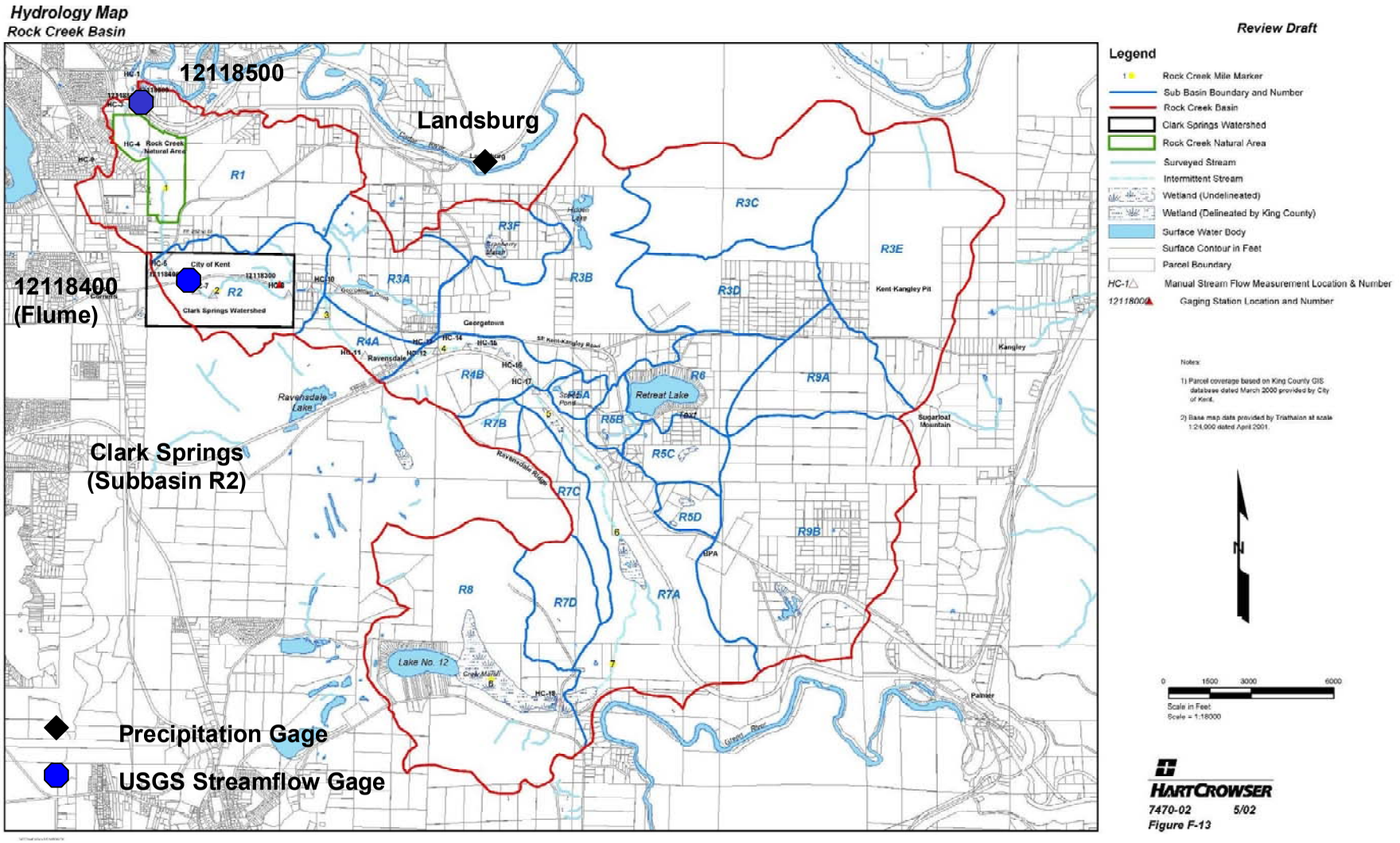



Figure 2 – Rock Creek Watershed Subbasins

***Geology***
The geology of the watershed was based on information collected from various existing geologic map sources as described by Hart Crowser in their Hydrogeologic Report[7] for the project. For hydrologic modeling purposes, each geologic association was assigned to one of four categories (till, outwash, ice contact, or wetland) as shown in Table 1.

**Table 1 – Surficial Geologic Associations and Relationship to HSPF Geology Categories**

| Geologic Association | Geologic Code | HSPF Category |
|---|---|---|
| Advance Outwash | Qva | Outwash |
| Recessional Outwash | Qvr | Outwash |
| Till | Qvt | Till |
| Bedrock | Tbr | Till |
| Ice Contact | Qvi | Ice Contact |
| Wetland | Qlp | Wetland |

Wetlands were also defined as a land cover based on the presence of wetland vegetation. Areas defined as wetland based on land cover were assigned to the wetland HSPF category regardless of the underlying geology.

***Land Cover***
Four land use scenarios were evaluated including historic (1944), 1968, current (1999), and future build-out. Land use for 1944, 1968, and 1999 scenarios were derived by analysis of air-photo and GIS coverage of the watershed, prepared for the study by Hart Crowser[7]. Land use for future build-out conditions was determined based on King County zoning maps.

Five land cover categories were considered in analyzing the watershed hydrology; impervious, forest, urban grass, wetland, and pasture. The percentage of each cover allocated to the mapped land uses are shown in Table 2. The effective impervious surface areas were determined based on relationships with mapped impervious surface developed by Sutherland[8].

It was found that there was little difference in the runoff response from the watershed for the various land use scenarios examined[3]. The reason for this is that the land use density in the watershed is mostly rural, and the runoff characteristics have changed little over the last 60-years. In addition, under current zoning ordinances, runoff characteristics would be expected to change little in the future. Another factor mitigating changes to the runoff characteristics with urbanization is the highly infiltrative glacial outwash deposits in the watershed. Surface runoff from developed parts of the watershed infiltrates into the outwash deposit. This greatly attenuates the runoff response from urban areas and provides some additional groundwater volume in the summer months.

**Table 2 – Land use and Percentage of HSPF Cover Categories**

| Land Use | Effective Impervious | Forest | Grass | Wetland | Pasture |
|---|---|---|---|---|---|
| Commercial/Industrial | 85% | 0% | 15% | 0% | 0% |
| Forest | 0% | 100% | 0% | 0% | 0% |
| Grass | 0% | 0% | 100% | 0% | 0% |
| High Density Residential | 25% | 0% | 75% | 0% | 0% |
| Medium Density Residential | 10% | 0% | 90% | 0% | 0% |
| Mixed Grass and Forest | 0% | 50% | 50% | 0% | 0% |
| Railroad and Rails to Trails | 10% | 0% | 90% | 0% | 0% |
| Arterial Roads | 50% | 0% | 50% | 0% | 0% |
| Rural Residential Forest | 4% | 96% | 0% | 0% | 0% |
| Rural Residential Grass | 4% | 0% | 0% | 0% | 96% |
| Wetlands/Open Water | 0% | 0% | 0% | 100% | 0% |

***Stream Definition/ Channel Routing***

Runoff computed by the HSPF model is routed through the stream system using a Kinematic Wave hydrologic routing algorithm. The principal input for this routine is a stage-storage-discharge rating table, called an *FTABLE,* which is developed for each subbasin. In general, channel routing has little effect on hydrograph shape in the Rock Creek watershed due to the attenuated nature of the groundwater-dominated discharge. FTABLES developed by King County as part of the model developed for the Cedar River Basin Plan[2] were adopted for use in the current analysis with the exception of the FTABLE representing the diversion to the Green River near the Rock Creek headwaters.

A diversion channel was constructed downstream of the outlet of subbasin R8 in the early 1960's and remained in operation until 1995 when it was dammed. This channel discharged a maximum of about 3 cfs to the Green River basin with the diversion drying up during times of low flow. The diversion was included in simulations for time periods when it operated historically. The discharge characteristics of the diversion channel were based on field survey performed as part of this study

***Development of Precipitation Timeseries for Hydrologic Analyses***

Mean annual precipitation maps developed by Oregon Climate Service[9] using a GIS analysis approach, called PRISM, were used to define the variability of precipitation over the Rock Creek watershed (Figure 3). Mean annual precipitation varies from 52 inches to 68 inches in an easterly direction across the watershed in response to the orographic influence of the Cascade Mountains. The watershed mean annual precipitation was determined to be 59 inches using the PRISM information.

Timeseries representative of the areas of the watershed with mean annual precipitation of 56 inches and 60 inches were developed by scaling hourly precipitation data collected from 1954 through 1998 at the Landsburg Gage (station number 45-4486) using a series of scaling functions. Evaporation timeseries for the same period were developed using a

stochastic computation approach whereby daily evaporation was generated in a manner that preserved the daily and seasonal variability while accounting for differences observed on rainy versus rain-free days. Details regarding the development of the precipitation and evaporation timeseries can be found in the report*; Extended Precipitation Time-Series for Continuous Hydrological Model in Western Washington,* MGS Engineering Consultants, Inc., 2002[10,11].

The majority of the hourly Landsburg precipitation record was missing for the February 2002 to February 2003 calibration period. Data from the daily gage at Landsburg was disaggregated to hourly and used as input to the model for this period. The diaggregation was performed by distributing the daily data according to the observed hourly pattern at King County gage 31Z, which is located approximately three miles north of the Rock Creek watershed.

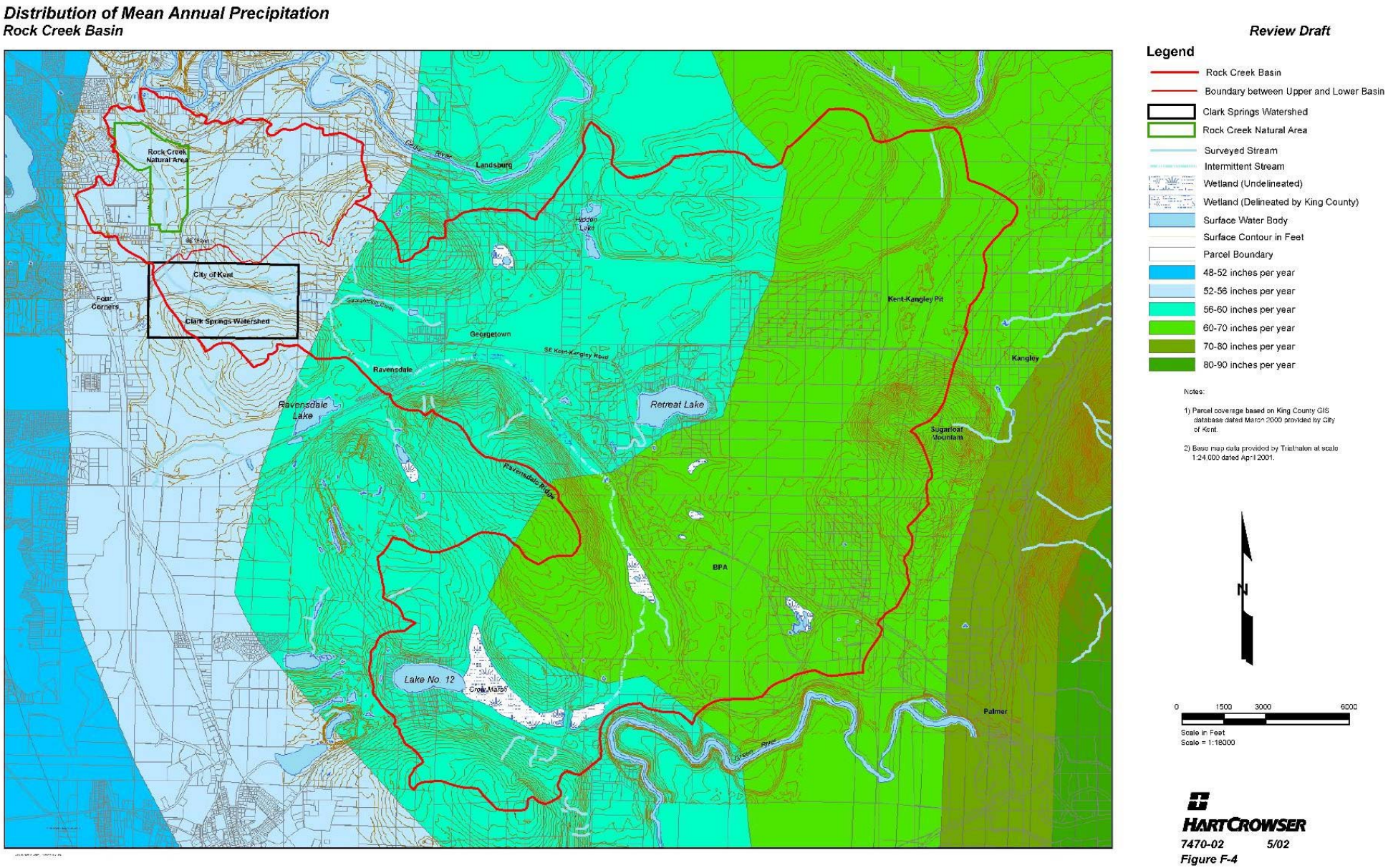



**Figure 3 – Mean Annual Precipitation Map of Rock Creek Watershed based on Oregon Climate Service PRISM' Model**

***HSPF Model Representation of the Clark Springs Water Supply System***

A map of the Rock Creek watershed showing model subbasins and the location of the Clark Springs Water Supply System (CSWSS) is shown in Figure 1. The CSWSS includes a structure called the *infiltration gallery* that is buried about 17 feet below the ground surface (Figure 4). Flow enters the infiltration gallery by gravity (without pumping) effectively capturing a portion of the groundwater flowing in the aquifer through and above the gallery. Capture of the groundwater results in a reduction of the groundwater head near the gallery leading to a reduction of the local base flow to Rock Creek. Thus, the water withdrawn from the infiltration gallery is composed of surface flow in Rock Creek and groundwater flow in the gravels above the intake pipe. The Clark Springs facility also includes three wells that draw water from a depth of 30 to 60 feet from the unconfined aquifer beneath the facility. These wells are seldom used and the majority of water supply withdrawals are taken through the infiltration gallery.

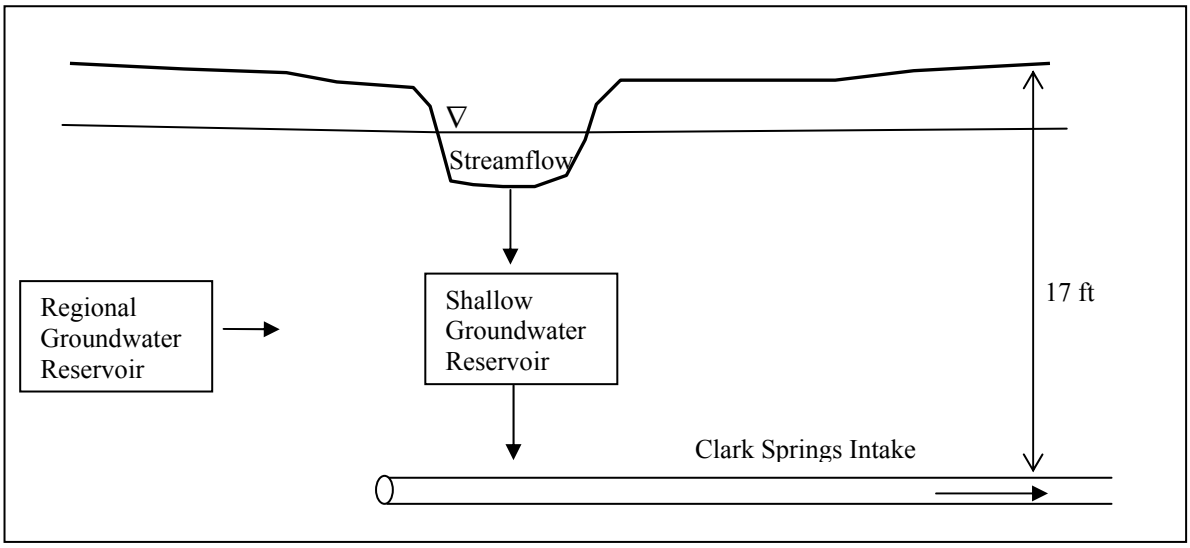



**Figure 4 – Cross Section of Rock Creek in Vicinity of Clark Springs Infiltration Gallery Showing Contribution of Streamflow and Shallow Groundwater**

The hydraulic characteristics of the Shallow Groundwater Reservoir indicated in Figure 4 were developed with essentially a bi-modal response depending on the amount of groundwater in the system. Based on withdrawal tests it was found that during the wet season when the regional groundwater is high, the streamflow response to water supply withdrawals is relatively quick, with a lag of approximately 2 days between the time when a demand is applied and the full effect is observed in the simulated streamflow[7,12].

In the summer and early fall months, there is a much longer lag between the time when withdrawal is applied and the response is seen in the streamflow. The longer lag is the result of the groundwater falling below the stream bottom and being less hydraulically connected to the creek. Under this condition, a lag of more than 100 days was observed between a change in withdrawal and streamflow rate[7,12].

***HSPF Model Schematic***

Simulated streamflow in Rock Creek and groundwater in the gravels above the infiltration gallery were available for withdrawal by the Clark Springs infiltration gallery. The remaining surface flow after applying the water supply withdrawals represented the flow in the perennial reach of Rock Creek through Subbasin R1, downstream of the CSWSS. Within this portion of the watershed, there was minimal additional runoff due to the predominant outwash deposits. In addition, the groundwater recharge in Subbasin R1 mainly appears to flow to the Cedar River, with very little entering Rock Creek.

A schematic of the HSPF model representation of the Rock Creek watershed is shown in Figure 5. Based on an examination of the catchment geology and the MODFLOW results[6], several flow paths were identified that remove groundwater from the catchment upstream of the Clark Springs Watershed. These included:

- Subbasin R3E – All groundwater from this subbasin flows north to the Cedar River missing the Clark Springs Watershed,
- Subbasin R3F – A portion of the groundwater flows north to the Cedar River through this subbasin,
- Subbasin R4A – A portion of the groundwater flows southwest towards Ravensdale Lake through this subbasin.

HSPF model calibration results are presented in the following sections.

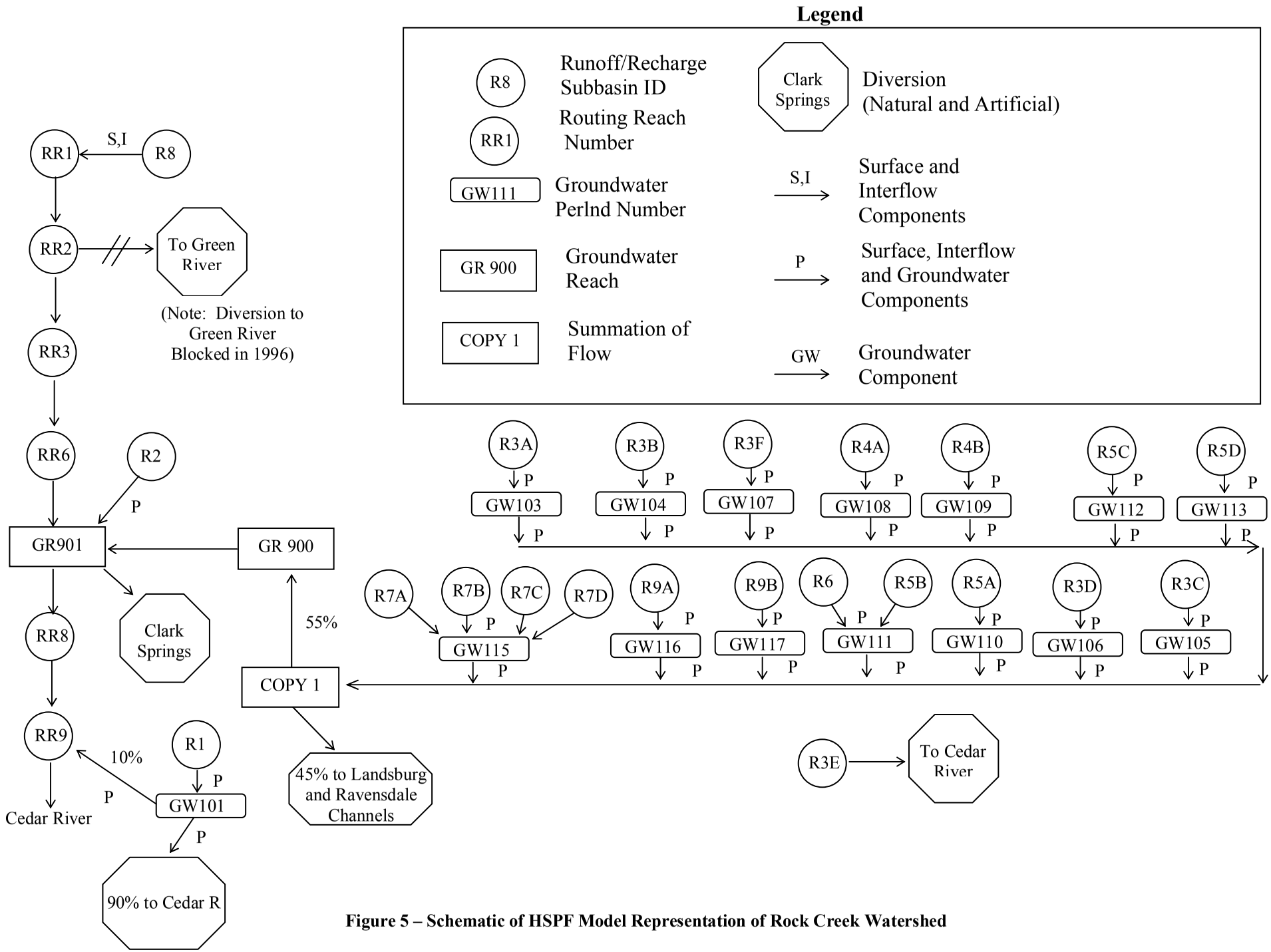



**Figure 5 – Schematic of HSPF Model Representation of Rock Creek Watershed**

## HSPF MODEL CALIBRATION

Calibration of the HSPF model was performed to ensure that the hydrologic processes simulated by the model were representative of the conditions in the Rock Creek watershed. In particular, the model must be capable of simulating withdrawals from the CSWSS and predicting low-flow conditions downstream. Hourly precipitation data were used as input to the model and the model parameters adjusted until simulated and recorded flow rates matched as closely as possible.

### *Calibration Periods/Data Availability*

Previous model calibration efforts[3,4] utilized data collected over three periods (Table 3). Calibration of the HSPF model was performed separately on each time period based on the availability of flow data. The same runoff parameter set was used for each calibration period with variations only for land use, the amount of withdrawals for water supply, and the presence or absence of the Green River diversion channel.

Recently, it was discovered that the streamflow measurements used previously in the second calibration period (water years 1986-1998) were over-estimated by up to 2.5 cfs due to downstream backwater at the Clark Springs flume. This streamflow information was corrected and the model recalibrated. Model calibration results presented in this report reflect the corrected streamflow data.

**Table 3 – HSPF Model Calibration/Validation Data Summary**

| Calibration Period | Calibration Flow Gage | Clark Springs Withdrawals | Precipitation Input* |
|---|---|---|---|
| Water Year 1955-1965 | USGS 12118500, Mean Daily<br>USGS 12118400, Mean Daily | 0.0 cfs – 0.5 cfs | Hourly Landsburg (Station 45-4486) |
| Water Year 1986-1998 | Flume at Clark Springs, Instantaneous Daily Reading | Withdrawal Records Used, Varied Daily, 6.2 cfs Average | Hourly Landsburg (Station 45-4486) |
| February 1, 2002 – February 28, 2003 | USGS 12118400 (Flume at Clark Springs) Recorded at 15-Minute Timestep, Aggregated to 1-Hour Timestep | Recorded at 15-Minute Timestep, Aggregated to 1-Hour Timestep | Daily Landsburg (Station 45-4486) Disaggregated Using King County Gage 31Z |

*Precipitation records were scaled to represent areas of 56 and 60 inches mean annual precipitation

***Model Simulation of Clark Springs Pump Test***

An HSPF reservoir routing element was used to simulate the apparent storage in the regional groundwater table that could not be accounted for with the HSPF groundwater simulation routine. When rain begins in autumn, there is a significant delay before the aquifer fills to the point it discharges to the creek. This was simulated using a routing element with volume/discharge (FTABLE) characteristics computed using the HSPF groundwater routine then refined through calibration. This approach added the flexibility to include more storage volume to provide the observed delayed response in the groundwater observed in the early fall.

A second reservoir element was included to simulate the flow attenuation that occurs as groundwater is withdrawn through the gravel above the intake. Water from the Regional Groundwater Reservoir and streamflow from Rock Creek are fed into the Shallow Groundwater Reservoir. Water remaining in the Shallow Groundwater Reservoir after applying withdrawals from Clark Springs is discharged back to Rock Creek.

The hydraulic characteristics of the Shallow Groundwater Reservoir used in the model were developed during the model calibration process. The hydraulic characteristics were verified by simulating withdrawal tests performed during a time of moderate discharge in Rock Creek (May 2001) and low discharge in Rock Creek (August 2004). The tests were performed by City staff by increasing the withdrawal through the Infiltration Gallery and monitoring the resulting change in streamflow at the flume for several days. The *depletion ratio* was computed by Hart Crowser as the change in observed streamflow at a subsequent time (dQ) divided by the change in withdrawal rate (Q) (Hart Crowser, 2004[12]). The depletion ratio varies with elapsed time as shown in Figure 6a, which was computed using data from the May 2001 and August 2004 tests.

Model simulation of the withdrawal tests performed in May and August of a typical water year (1995) showed close agreement with the observed lag times (Figure 6b). The simulated withdrawal responses shown in Figure 6b were computed using climatic data from water year 1995, because data from the hourly Landsburg precipitation gage used as input to the hydrologic model were not available for 2001 and 2004 when the tests were actually performed. The simulated results shown in Figure 6b would be similar for other water years as well. Simulation of the infiltration gallery tests showed that the model is accurately replicating the physical processes of the water withdrawal at the Clark Springs infiltration gallery.

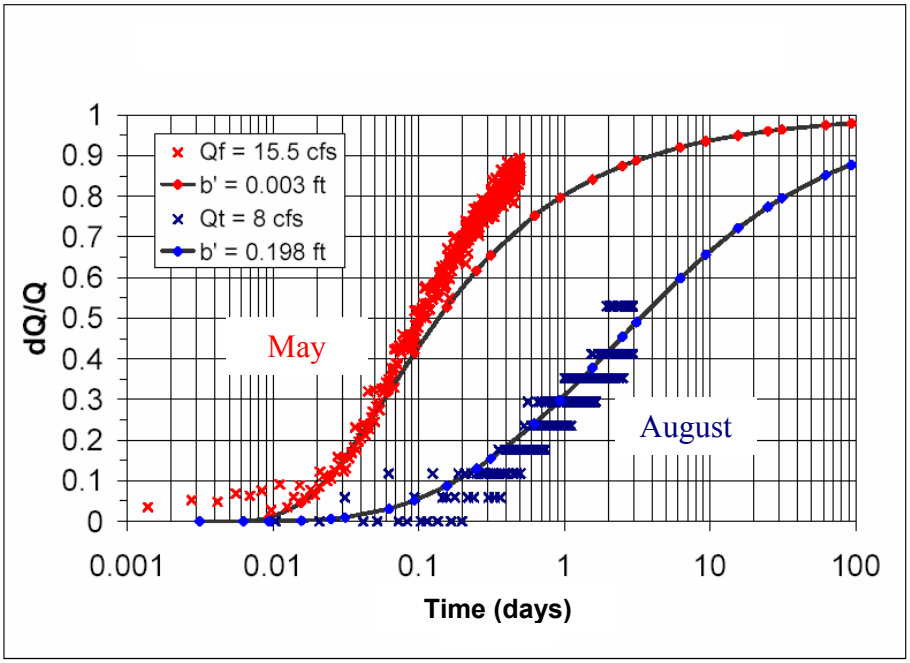



**Figure 6a – Clark Springs Infiltration Gallery Recorded Withdrawal Tests, May 2002 and August 2004**
**Data points represent Recorded Streamflow Change Computed as dQ/Q**
**Where: dQ=The Change in Observed Streamflow from the Start of the Test**
**Q=The total Change Applied to the Withdrawal Rate**
**(Figure Developed by Hart Crowser [7,12])**

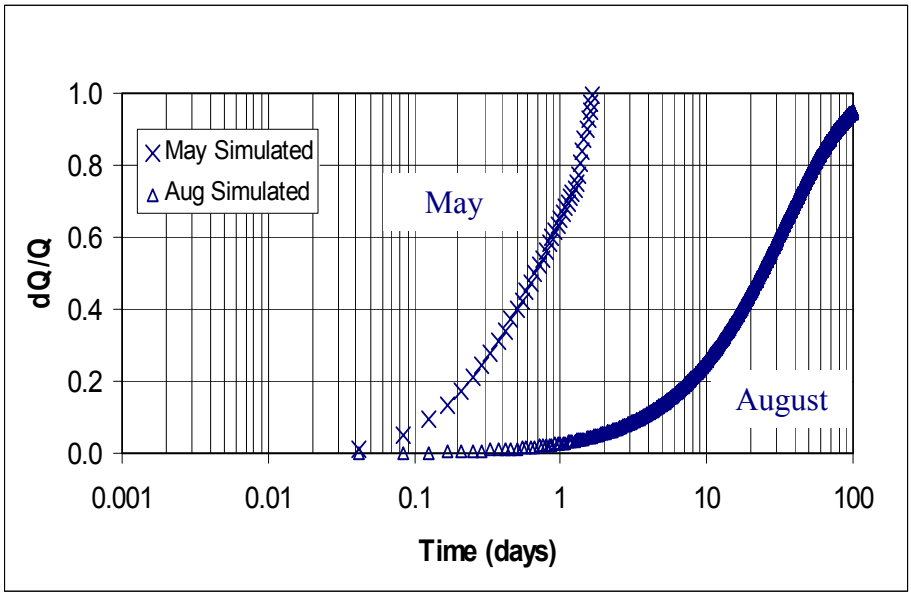



**Figure 6b – Clark Springs Infiltration Gallery, HSPF Simulated Withdrawal Tests, May 1995 and August 1995**
**(dQ= The Change in Observed Streamflow from the Start of the Test**
**Q=The total Change Applied to the Withdrawal Rate)**

***HSPF Model Calibration Approach***
Data from water years 1955-1965 and corrected data for the 1986-1998 period were used to calibrate the model. A third period (February 1, 2002-February 28, 2003) was used to validate the calibration. The 2002-2003 period represented a rigorous test for the model since it was one of the driest on record and included streamflow augmentation, a practice that did not begin until after the second calibration period.

After the model was validated, the 2002-2003 validation period was used to further refine the model calibration. This approach allowed for validation of the initial calibration parameter set and allowed for use of the validation data to further refine the accuracy of the model. The sections that follow present the initial model calibration, validation, followed by the final calibration achieved using the validation period to further refine the model calibration.

***Initial HSPF Model Calibration Results Water Years 1955-1965***
The HSPF model was calibrated to data collected from the 1955-1965 period using mean daily streamflow information from USGS gage 12118400 located at SR 516 and gage 12118500 located near the mouth of Rock Creek. No withdrawals were simulated with the HSPF model prior to the development of the Clark Springs water supply system in 1957. Records documenting the quantity of flow withdrawn did not begin until 1968 so the quantities withdrawn were unavailable for this period and the withdrawal rate was estimated through calibration to range from 0.0 to 0.5 cfs.

Calibration plots comparing simulated and recorded flows are shown in Figures 7-10. In general, close agreement was achieved between simulated and recorded hydrograph shape, summer low flows, and timing of peaks. In particular, very close agreement was achieved at USGS gage 12118400 located immediately downstream of Clark Springs (Figures 7-8).

It should be noted that this period reflects essentially natural conditions. The HSPF computational algorithms were quite successful in simulating the natural watershed conditions. The construction of the infiltration gallery, withdrawals for water-supply, and initiation of low-flow augmentation, which were present in later calibration periods, increased the difficulties and uncertainties of modeling this interactive surface-water and ground-water system.

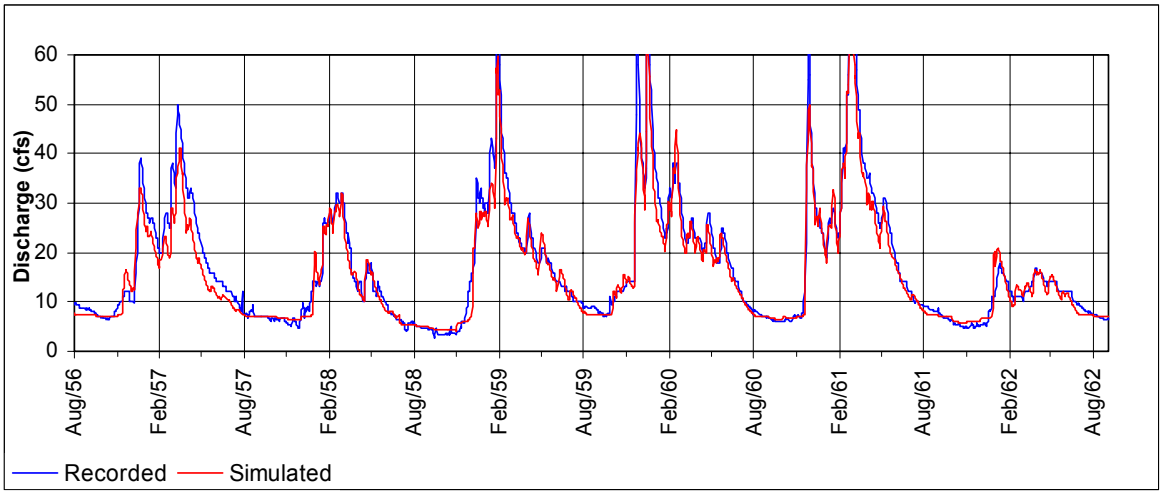



**Figure 7 – Initial HSPF Model Calibration**
**Rock Creek at SR 516 (USGS 12118400), Water Years 1957 through 1962 (mean daily discharge)**

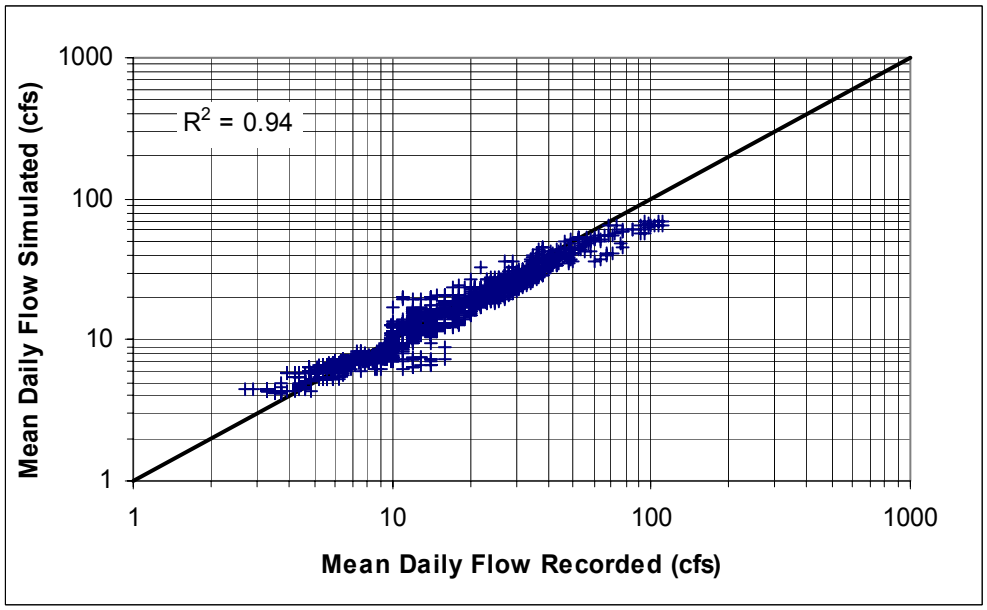



**Figure 8 – Initial HSPF Model Calibration**
**Rock Creek at SR 516 (USGS 12118400), Water Years 1957 through 1962 (mean daily discharge)**

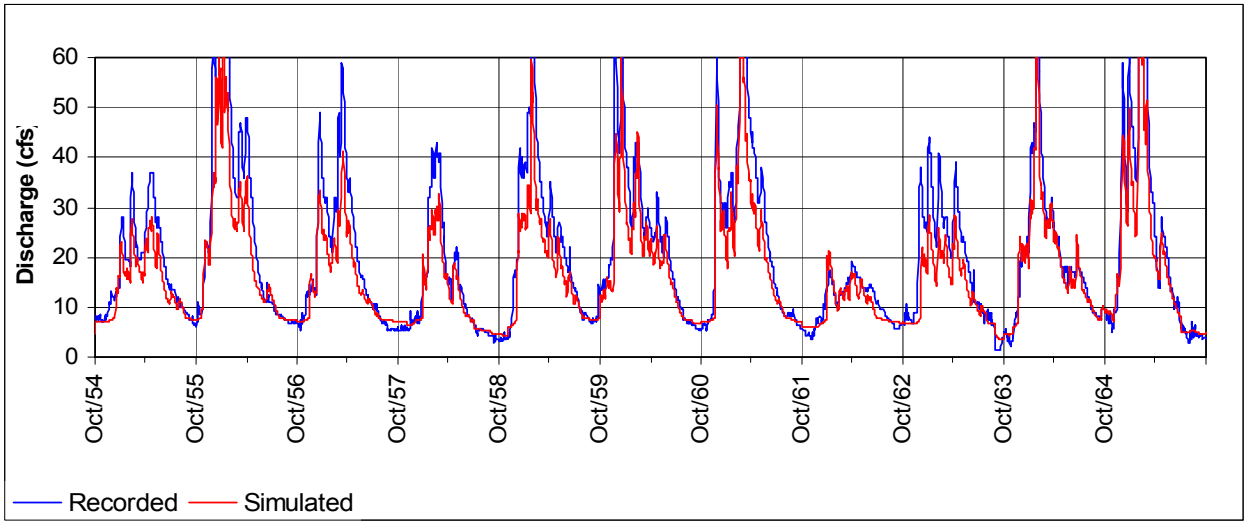



**Figure 9 – Initial HSPF Model Calibration**
**Rock Creek Near Mouth (USGS 12118500), Water Years 1955 through 1965 (mean daily discharge)**

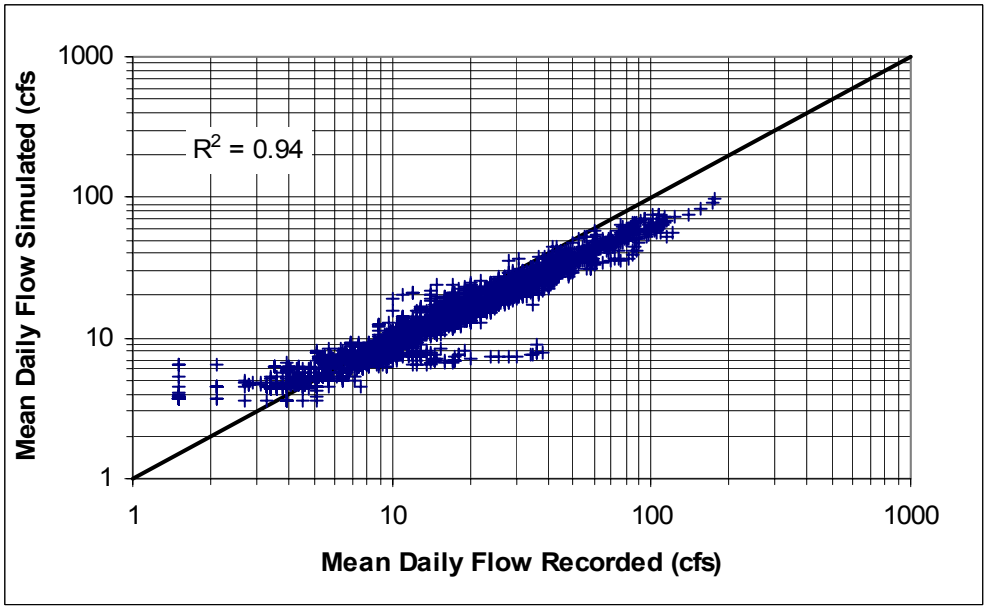



**Figure 10 – Initial HSPF Model Calibration**
**Rock Creek Near Mouth (USGS 12118500), Water Years 1955 through 1965 (mean daily discharge)**

***HSPF Model Calibration Results Water Years 1966-1973***

Streamflow data were available at USGS gage 12118500, located at the mouth of Rock Creek for the period 1966 through 1973. This period was broken out separately because the withdrawals at Clark Springs increased, and a channel was constructed at the outlet of Subbasin R8, which diverted a portion of the surface flow to the Green River. The calibration ended in 1973 because operation of USGS gage 12118500 was discontinued. Land use corresponding to 1968 conditions was used for the simulation of this period.

Withdrawal rates simulated in the model for 1968 through 1973 were based on monthly records kept by the City of Kent. Records of the quantity of flow withdrawn were not available prior to 1968, therefore the average quantity withdrawn was determined through calibration to be 2.0 cfs in 1966 and 2.5 cfs in 1967.

Figure 11 shows that simulated summer low flows were typically higher than recorded for this period. A scatter plot comparison between simulated and recorded mean daily discharge (Figure 12) shows a model over-prediction bias with the highest percentage error at low discharge rates (less than about 10 cfs).

The over-prediction bias could not be corrected for this calibration period without introducing errors and bias into the simulations for the other calibration periods. For example, if the parameters controlling the discharge from the outwash were changed such that the summer low flow values better matched the recorded for this period, then the model would underestimate summer low flows for 1955-1965 and 1985-1998 simulation periods.

Annual withdrawal rates in the 1966 through 1973 period were roughly half of current levels with nearly average annual precipitation. Given this input data, it makes no physical sense that the gaged minimum low flows would be lower for this period than the 1985 to 1998 period when withdrawal rates were nearly double.

After reviewing the calibration results for this period, and recognizing the likely sources of data input error, it was decided to utilize the calibration results from the 1955-1965 and 1985-1998 periods where greater confidence could be placed in the basic data inputs. The data from USGS gage 12118500 from 1966 through 1973 were not used for model calibration.

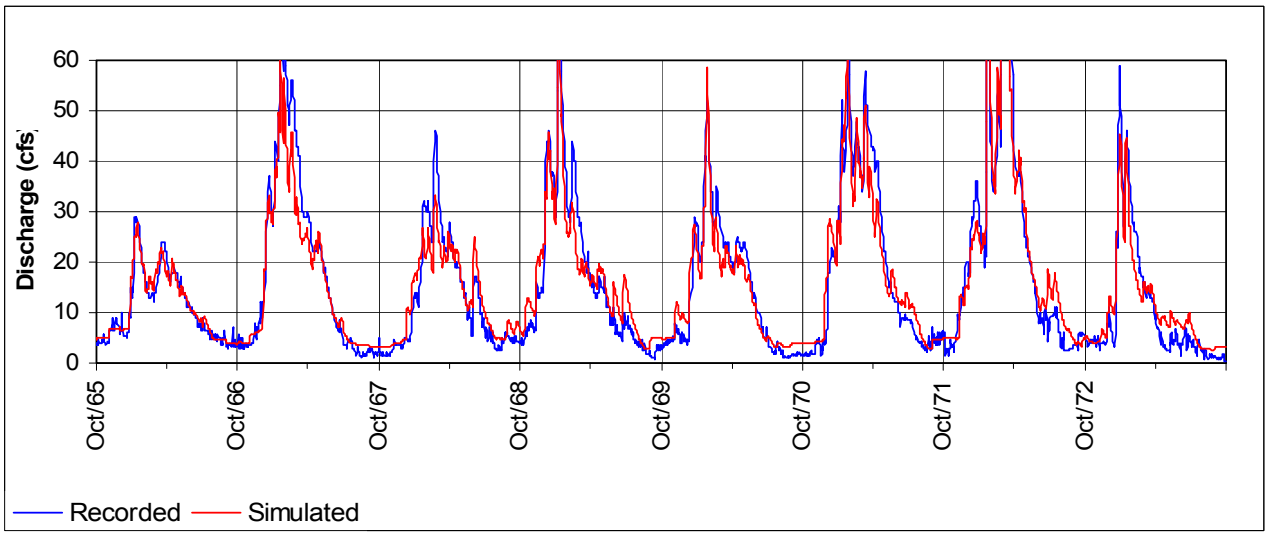



Figure 11 – HSPF Model Calibration
Rock Creek Near Mouth, Water Years 1966 through 1973

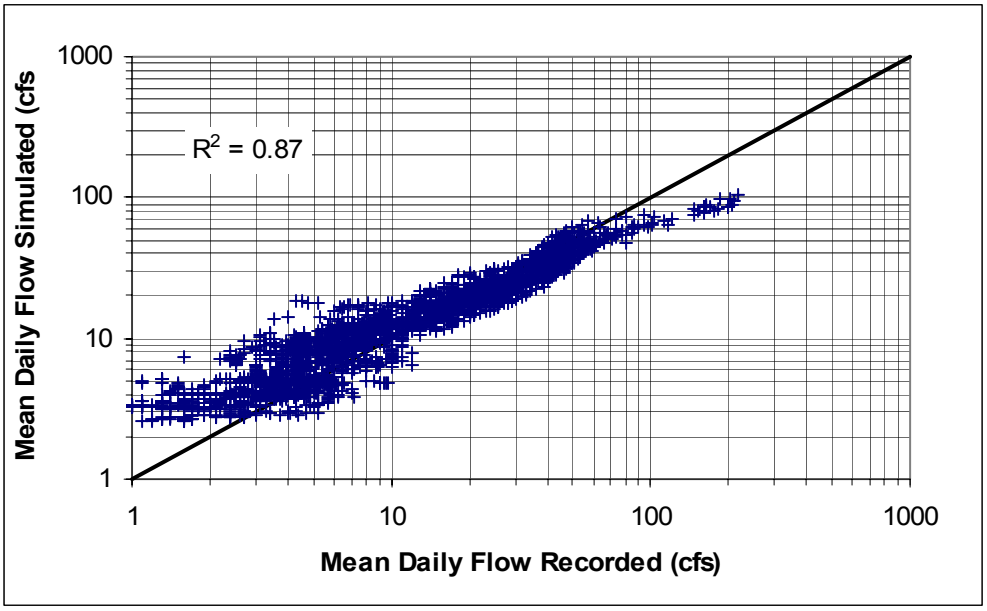



Figure 12 – HSPF Model Calibration
Rock Creek Near Mouth, Water Years 1966 through 1973

***Initial HSPF Model Calibration Results Water Years 1985-1998***

Flow data collected at Clark Springs by the City of Kent were used to calibrate the HSPF model for the period from 1985 through 1998. Discharge measurements were made once daily by the City of Kent using a Parshall flume located immediately downstream of the project and used as an estimate of the average streamflow for the day. Data for this period used in previous model calibration efforts were found to be over-estimated by up to 2.5 cfs due to backwater effects at the flume. The data were corrected for the model calibration presented in this report.

The flume generally provides reasonable estimates at low discharge; however, the capacity of the flume was exceeded during many winter storms when the streamflow exceeded 35 cfs. Periods of missing data also occurred from time-to-time, which made it difficult to compute meaningful runoff volume statistics for comparison with the simulated flows. The 1999 land use coverage was used for this calibration period.

In general, the timing and magnitude of simulated summer low flows matched the data recorded at the flume (Figures 13 and 14). More variability between simulated and recorded was noted in this period relative to the previous calibration period. This is likely due to the added uncertainty of the streamflow measurements which were taken once per day during this period, as compared with the continuous streamflow measurements used in the previous calibration periods and the higher rates of withdrawal that occurred from the CSWSS.

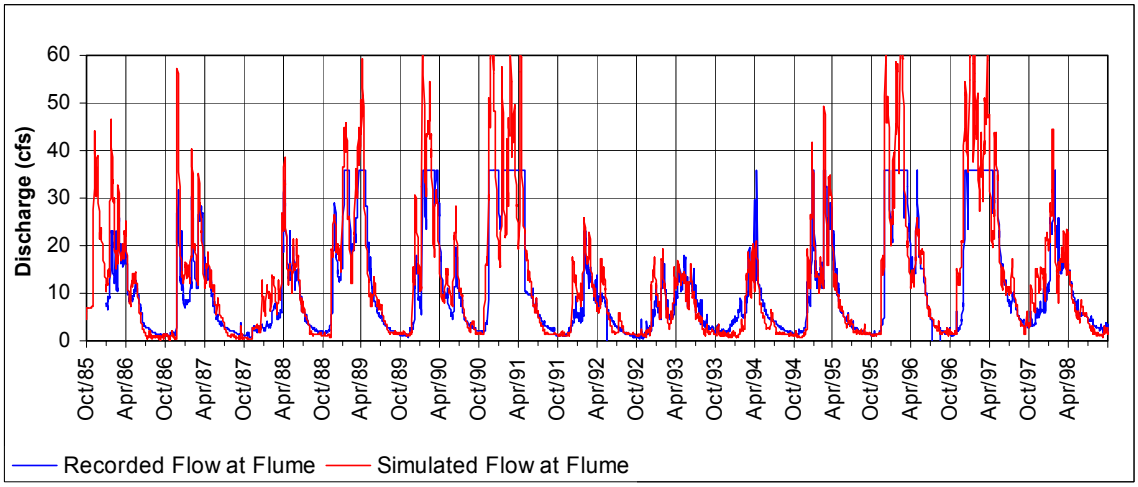



**Figure 13 – Initial HSPF Model Calibration**
**Rock Creek at Clark Springs Flume, Water Years 1986 through 1998**
**(Recorded Mean Daily Withdrawal was used in the HSPF model to Simulate Clark Springs Water Supply Operations)**

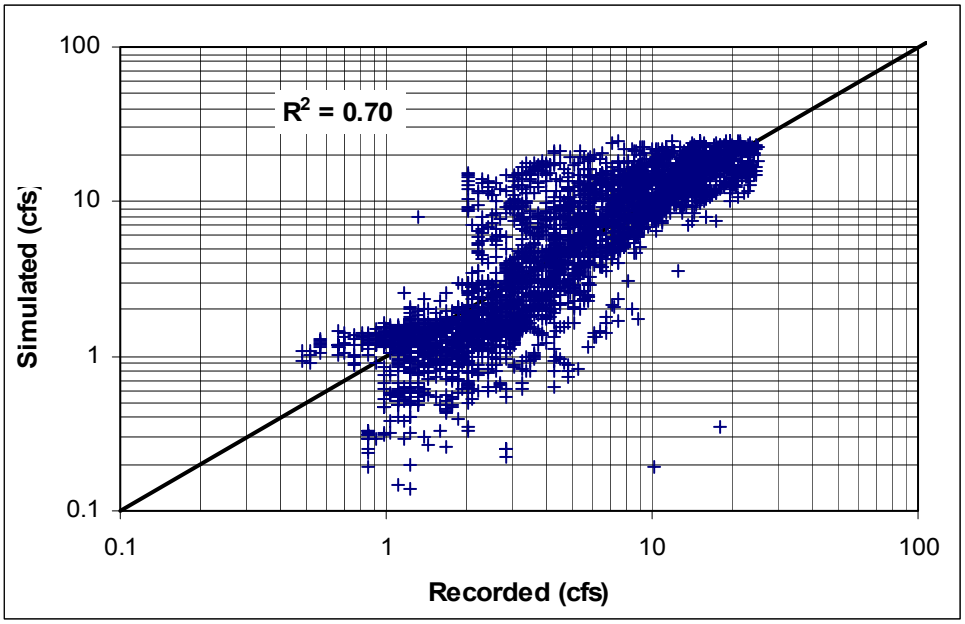



**Figure 14 – Initial HSPF Model Calibration**
**Rock Creek at Clark Springs Flume, Water Years 1986 through 1998**
**(Recorded Mean Daily Withdrawal was used in the HSPF model to Simulate Clark Springs Water Supply Operations)**

***HSPF Model Validation Results February 2002-February 2003***
Model input calibrated to the previous periods (1955-1965 and 1986-1998) was validated using data collected from February 1, 2002 through February 28, 2003. The 2002-2003 period included streamflow augmentation, a practice that did not begin until after the second calibration period. During times of low streamflow, the City diverts a portion of the flow from the infiltration gallery back to the stream to augment streamflow.

The fall of 2002 was exceptionally dry and represented a rigorous test for the model. Figure 15 shows the cumulative departure from the mean precipitation beginning March 1, 2002. Precipitation in the fall of 2002 was well below normal with a maximum cumulative deficit of 10.6 inches reached by early December. The precipitation that did fall during the autumn months resulted in little increase in streamflow.

**Figure 15 – Cumulative Precipitation from March 1, 2002 Expressed as Cumulative Departure from the Mean (Precipitation from King County Gage 31Z)**

The majority of the hourly Landsburg precipitation record, which was used as input to the model for the previous calibration periods, was missing for the February 2002 to February 2003 period. Data from the daily gage at Landsburg was disaggregated to hourly and used as input to the model for this period. The disaggregated precipitation used as input for this period likely added additional simulation error relative to the previous calibration periods.

Results of the model validation (Figures 16 and 17) shows that the streamflow augmentation practice is well addressed by the model, with a close match between simulated and recorded streamflow during the summer and fall months. Model over simulation of streamflow near the end of the augmentation period is likely due to precipitation variability, with higher precipitation falling at the gage than over the Rock Creek watershed.

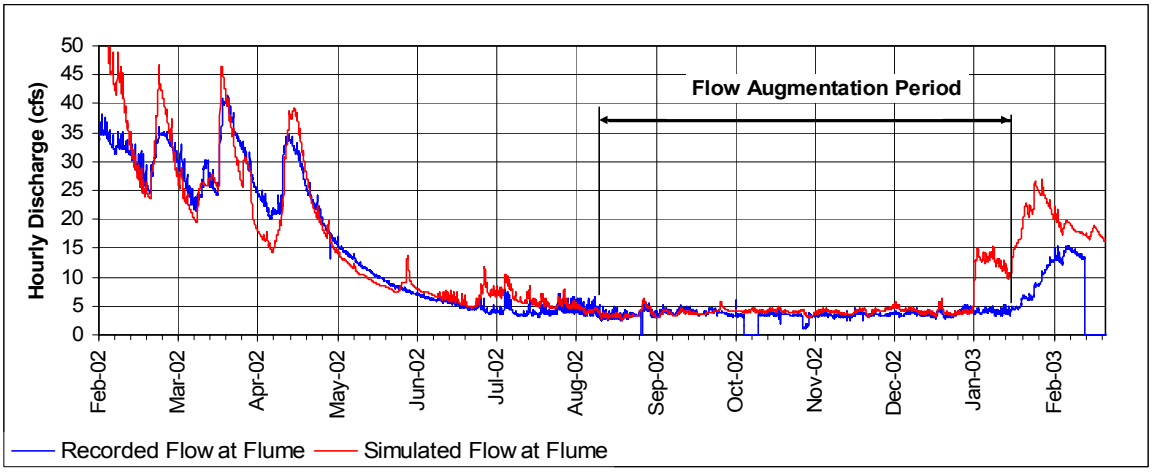



**Figure 16 – HSPF Model Validation, Rock Creek at Clark Springs Flume**
**February 2002-February 2003**
**(Hourly Recorded Flow Extracted was used as Input to HSPF to Simulate**
**Clark Springs Water Supply Withdrawals)**

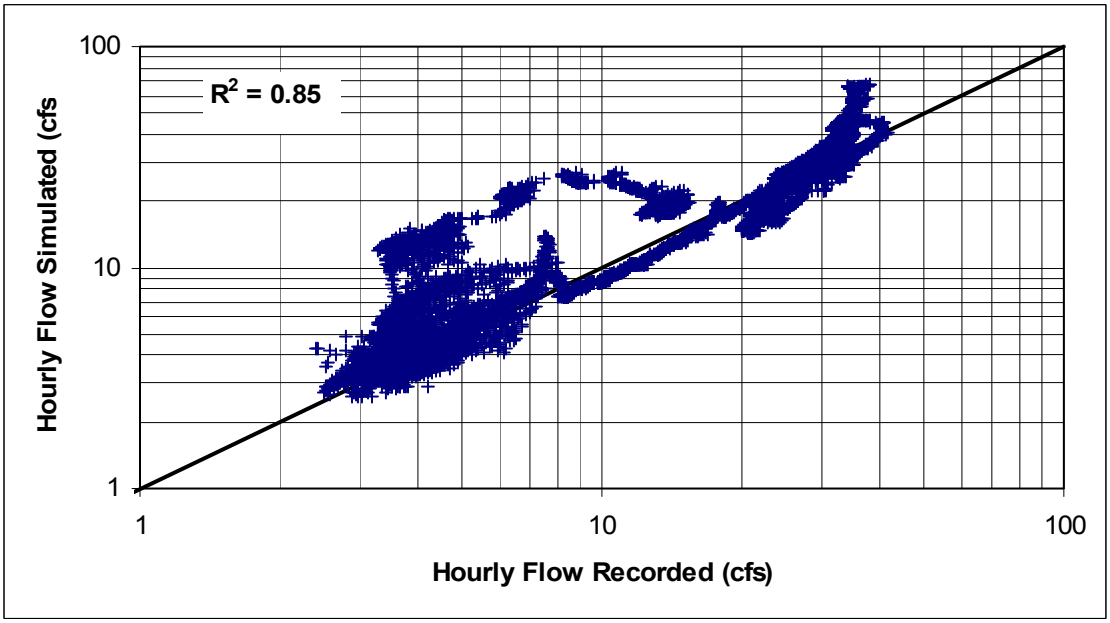



**Figure 17 – HSPF Model Validation Rock Creek at Clark Springs Flume**
**February 2002-February 2003**
(Hourly Recorded Flow Extracted was used as Input to HSPF to Simulate
Clark Springs Water Supply Withdrawals)

## FINAL HSPF MODEL CALIBRATION RESULTS

This section presents the results of the final model calibration achieved using the 2002-2003 validation period to further refine the model predictions. In general, the final model calibration was improved relative to the initial results presented previously. Final calibration plots comparing simulated and recorded streamflows are shown in Figures 18-25. A comparison between simulated and recorded low-flow runoff volume for the 1955-1965 calibration period is presented in Tables 4a and 4b. Volumetric comparisons for later calibration periods were not included because of gaps in the streamflow record. In general, the hydrograph shape, summer low flows, and timing of peaks were improved over the initial calibration. Final HSPF runoff parameters are summarized in Tables 5a and 5b.

The difference between simulated and recorded discharge varied among the three calibration periods with the earlier period (1955-1965) producing the closet match between simulated and recorded discharge, with simulated and recorded low-flow runoff volume within 5%. This period represents essentially natural conditions with little withdrawal from Clark Springs. The later calibration periods included withdrawal and the 2002-2003 period included withdrawal and augmentation. The withdrawal and augmentation data, which were used as model inputs, added additional variability to the calibration due to the inherent uncertainty in estimating these values.

The model representation of the shallow groundwater interactions in the vicinity of Clark Springs also contributed to differences between simulated and recorded streamflow in the calibration. Simulation of the groundwater/surface water interaction near the Clark Springs intake was difficult using HSPF, which was developed as a surface water model. The conceptualization of Clark Springs using the HSPF routing elements to represent the shallow groundwater reservoir replicated the approximate time lag of withdrawal curtailment tests; however, it is a simplified representation of the process by which water is withdrawn through the gravel by infiltration gallery. Nonetheless, this approach does provide reasonable accuracy in simulating the Clark Springs Water Supply System as evidenced by the close fit between simulated and recorded low flows. The emphasis of this analysis is on low flow periods and the model matched the gage record well during these times. Simulated and recorded discharge rates were within 8% for rates less than 6 cfs for the February 2002 to February 2003 period (Figures 24 and 25).

In summary, model calibration results show sufficiently close agreement between simulated and recorded streamflow for the more than 32-years of data used in the calibration indicating that the model accurately simulates Rock Creek streamflow for a variety of climatic, withdrawal, and streamflow augmentation conditions. Thus, the model is valid as a tool for examining the effects of water withdrawal and augmentation scenarios on streamflow.

**Table 4a – Comparison of Simulated and Recorded Annual Low-Flow Runoff Volume Water Years 1957-1961 (Computed using Discharges Less Than 10 cfs) USGS Gage 12118400, Rock Creek Near SR 516**

| Water Year | Clark Springs Mean Withdrawal (cfs) | Simulated Runoff (inches) | Recorded Runoff (inches) | Percent Error* |
|---|---|---|---|---|
| 1957 | 0.1 | 2.11 | 2.24 | -5.8% |
| 1958 | 1.3 | 3.05 | 3.16 | -3.4% |
| 1959 | 0.8 | 1.84 | 2.05 | -10.2% |
| 1960 | 0.6 | 1.46 | 1.52 | -4.2% |
| 1961 | 0.5 | 2.28 | 2.45 | -6.9% |
| **Average Percent Error** | | | | **-5.4%** |

*Computed as (Simulated-Recorded)/Recorded

**Table 4b – Comparison of Simulated and Recorded Annual Low-Flow Runoff Volume Water Years 1955-1966 (Computed using Discharges Less Than 10 cfs) USGS Gage 12118500, Rock Creek Near Maple Valley**

| Water Year | Clark Springs Mean Withdrawal (cfs) | Simulated Runoff (inches) | Recorded Runoff (inches) | Percent Error* |
|---|---|---|---|---|
| 1955 | 0 | 1.87 | 1.92 | -2.5% |
| 1956 | 0 | 2.19 | 2.23 | -1.5% |
| 1957 | 0.1 | 2.10 | 1.98 | 6.0% |
| 1958 | 1.3 | 3.21 | 3.32 | -3.3% |
| 1959 | 0.8 | 1.88 | 1.94 | -3.2% |
| 1960 | 0.6 | 1.28 | 1.23 | 4.4% |
| 1961 | 0.5 | 2.34 | 2.44 | -4.0% |
| 1962 | 0.9 | 2.62 | 2.76 | -5.3% |
| 1963 | 0.4 | 2.22 | 2.31 | -4.0% |
| 1964 | 0.7 | 1.60 | 1.81 | -11.3% |
| 1965 | 0.8 | 2.07 | 2.07 | -0.1% |
| 1966 | 1.9 | 2.93 | 2.95 | -0.7% |
| **Average Percent Error** | | | | **-2.4%** |

*Computed as (Simulated-Recorded)/Recorded

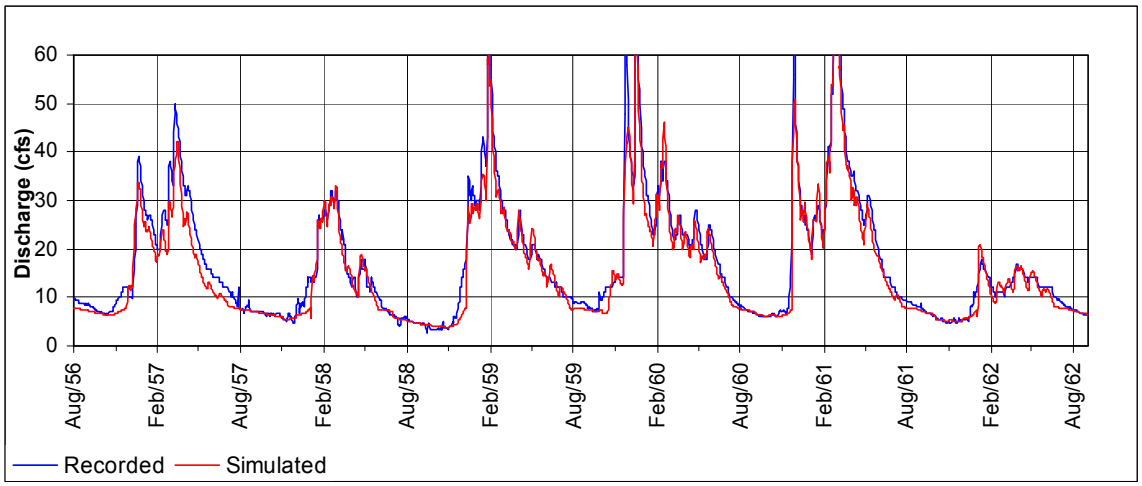



**Figure 18 – Final HSPF Model Calibration**
**Rock Creek at SR 516 (USGS 12118400), Water Years 1957 through 1962 (mean daily discharge)**

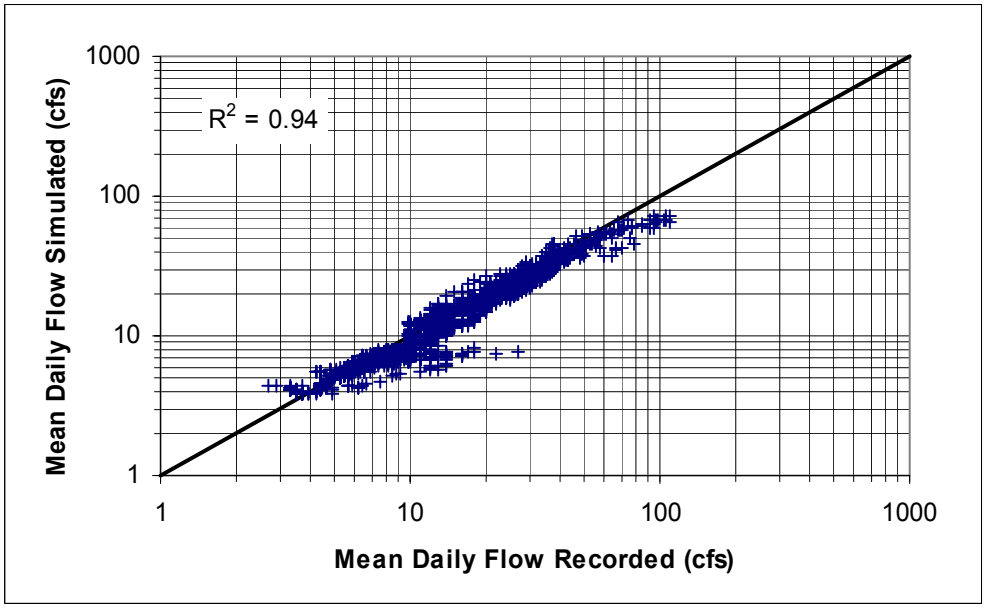



**Figure 19 – Final HSPF Model Calibration**
**Rock Creek at SR 516 (USGS 12118400), Water Years 1957 through 1962 (mean daily discharge)**

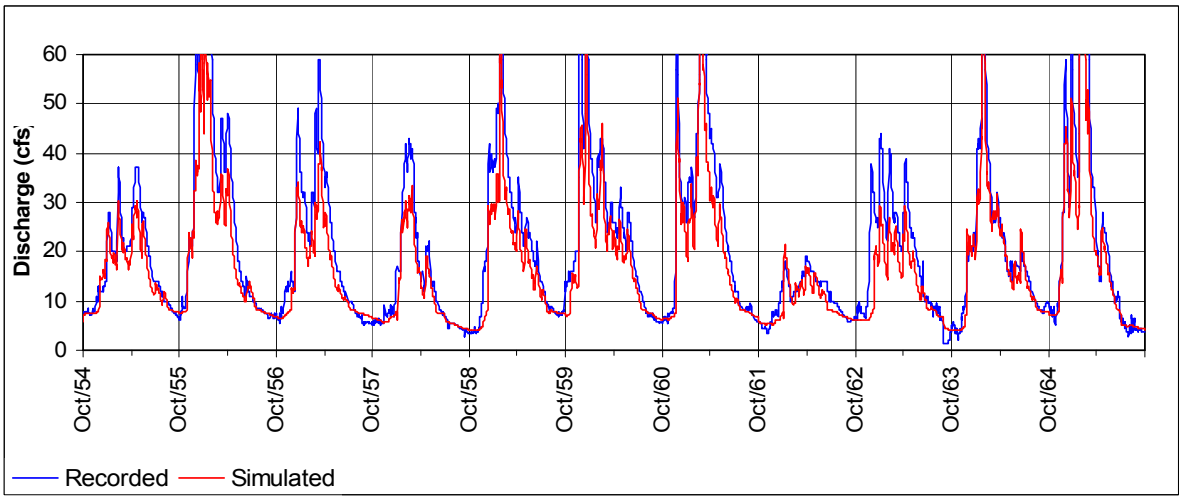



**Figure 20 – Final HSPF Model Calibration**
**Rock Creek Near Mouth (USGS 12118500), Water Years 1955 through 1965 (mean daily discharge)**

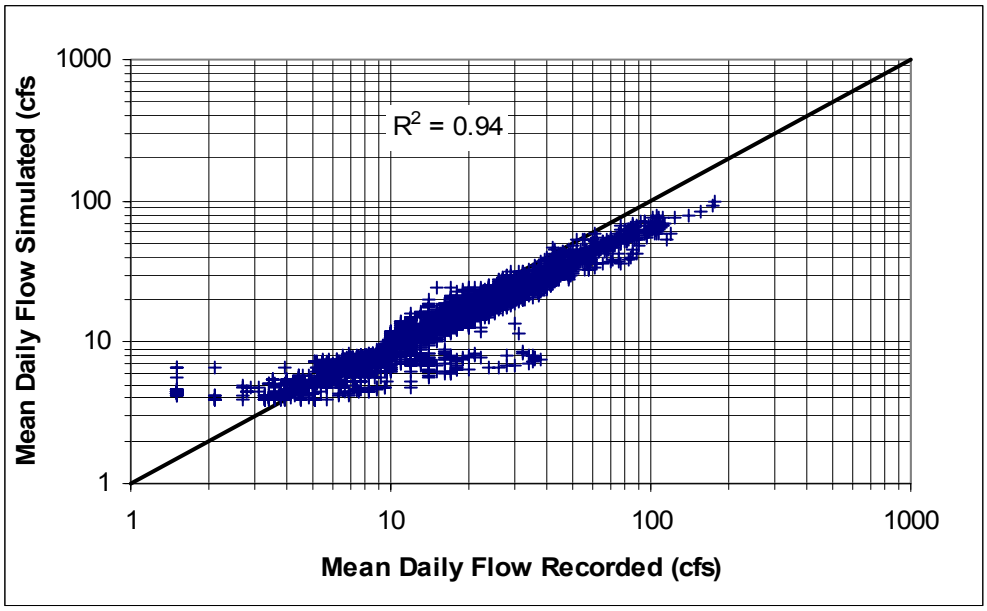



**Figure 21 – Final HSPF Model Calibration**
**Rock Creek Near Mouth (USGS 12118500), Water Years 1955 through 1965 (mean daily discharge)**

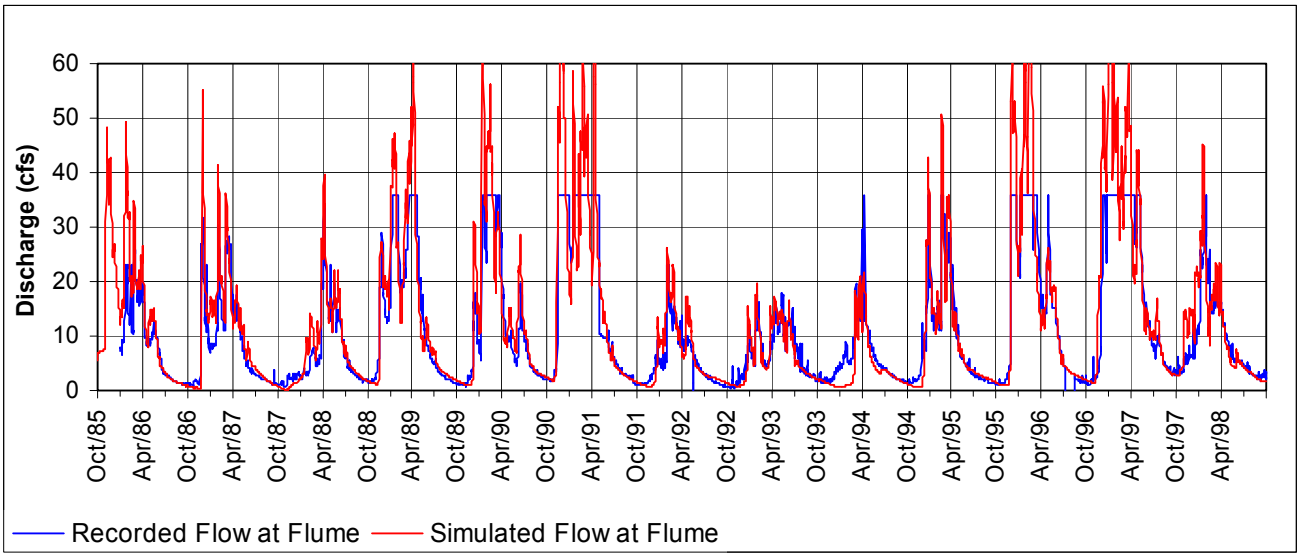



**Figure 22 – Final HSPF Model Calibration**
**Rock Creek at Clark Springs Flume, Water Years 1986 through 1998**
**(Recorded Mean Daily Flow Extracted was used as Input to HSPF to Simulate Clark Springs Water Supply Withdrawals)**

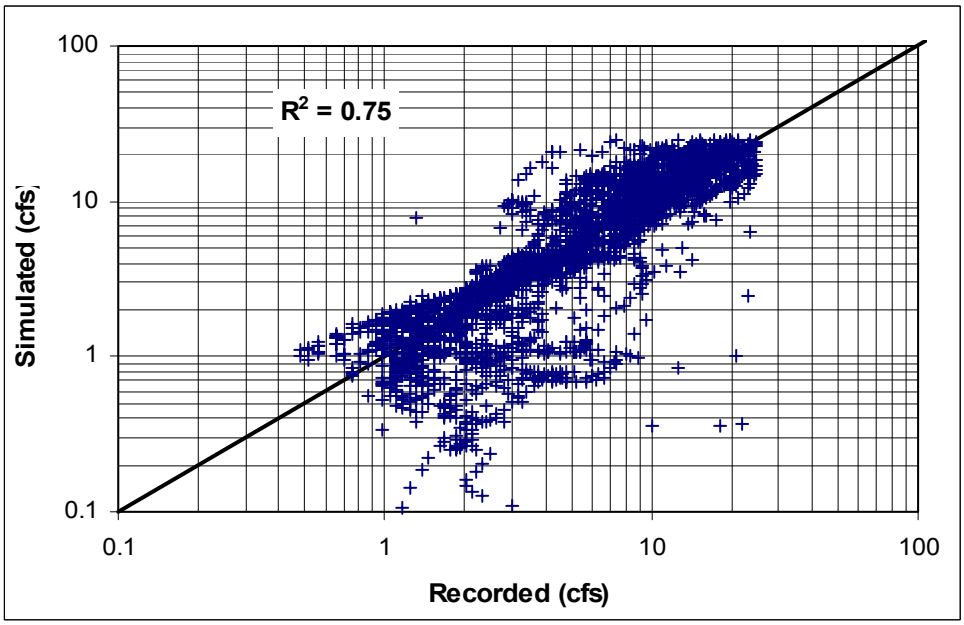



**Figure 23 – Final HSPF Model Calibration**
**Rock Creek at Clark Springs Flume, Water Years 1986 through 1998**
**(Recorded Mean Daily Flow Extracted was used as Input to HSPF to Simulate Clark Springs Water Supply Withdrawals)**

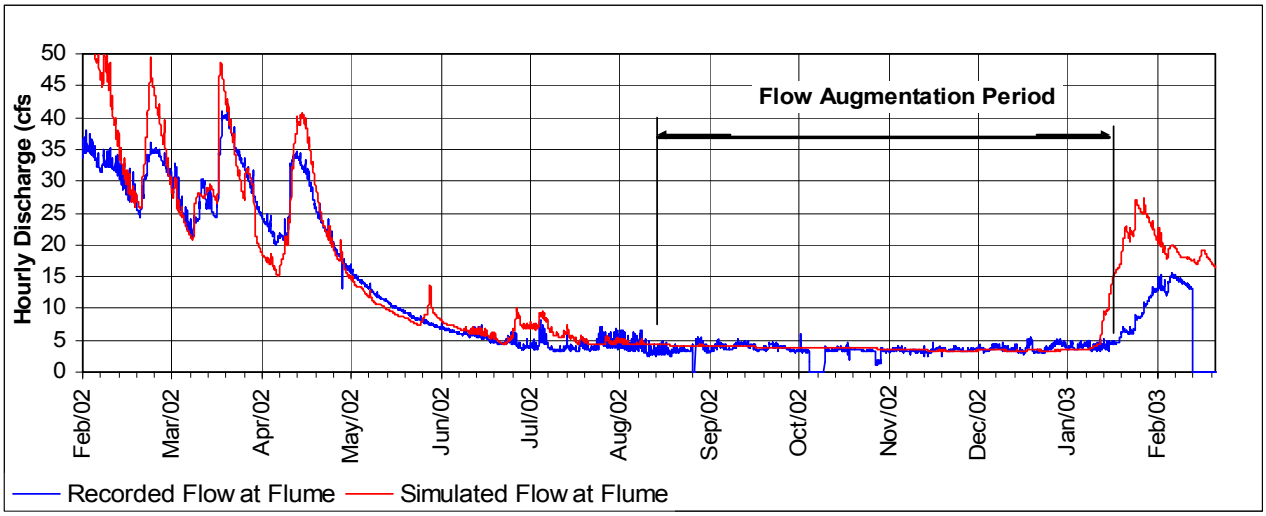



**Figure 24 – Final HSPF Calibration, Rock Creek at Clark Springs Flume**
**February 2002-February 2003**
**(Hourly Recorded Flow Extracted was used as Input to HSPF to Simulate Clark Springs Water Supply Withdrawals)**

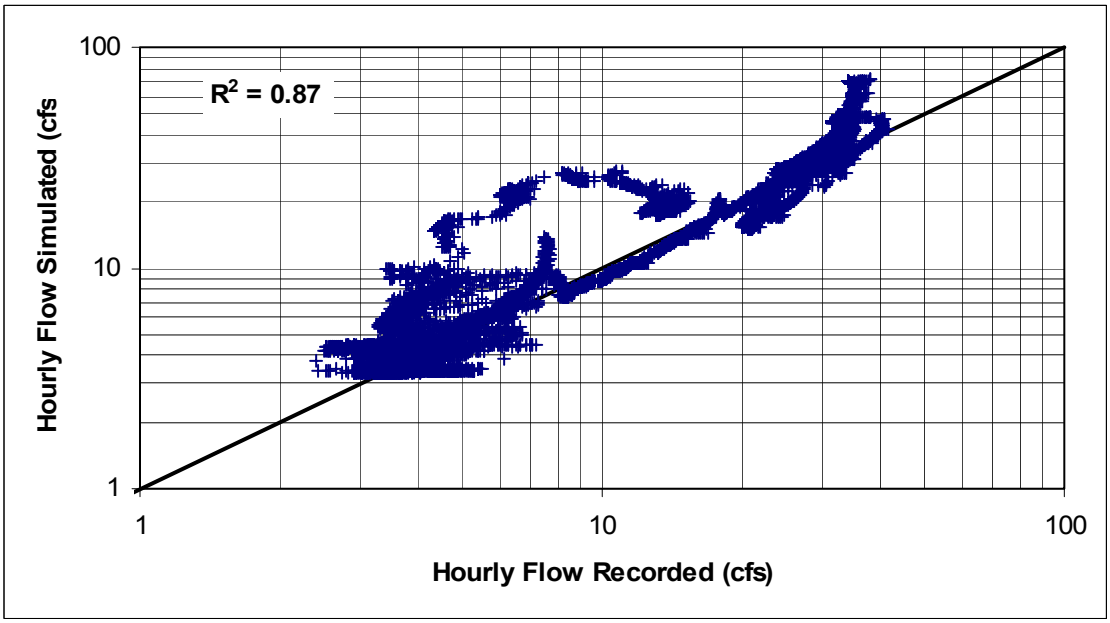



**Figure 25 – Final HSPF Calibration, Rock Creek at Clark Springs Flume**
**February 2002-February 2003**
**(Hourly Recorded Flow Extracted was used as Input to HSPF to Simulate Clark Springs Water Supply Withdrawals)**

**Table 5a – Calibrated HSPF Parameter Set for Pervious Areas with (Strikeouts Indicate Changes From Original Parameter Set)**

| Pervious Land Type | FOREST | LZSN | INFILT | LSUR | SLSUR | KVARY | AGWRC |
|---|---|---|---|---|---|---|---|
| Till Forest | 0.75 | 4.50 | 0.08 | 400 | 0.10 | 0.50 | 0.997 |
| Till Pasture | 0.01 | 4.50 | 0.03 | 400 | 0.10 | 0.50 | 0.997 |
| Till Grass | 0.01 | 4.50 | 0.06 | 400 | 0.10 | 0.50 | 0.997 |
| Outwash/Ice Contact Forest | 0.75 | 5.00 | 2.00 | 400 | 0.05 | 0.50 | 0.997 |
| Outwash/Ice Contact Pasture | 0.01 | 5.00 | 0.80 | 400 | 0.05 | 0.50 | 0.997 |
| Outwash/Ice Contact Grass | 0.01 | 5.00 | 1.60 | 400 | 0.05 | 0.50 | 0.997 |
| Wetland | 0.75 | 4.00 | 2.00 | 100 | 0.00 | 0.50 | 0.997 |
| Groundwater Aquifer | 0.75 | 5.00 | 2.00 | 400 | 0.05 | 0.15 | 0.997 |

| Pervious Land Type | PETMAX | PETMIN | INFEXP | INFILD | DEEPFR | BASETP | AGWETP |
|---|---|---|---|---|---|---|---|
| Till Forest | 0.0 | 0.0 | 2.0 | 2.0 | 0.0 | 0.0 | 0.0 |
| Till Pasture | 0.0 | 0.0 | 2.0 | 2.0 | 0.0 | 0.0 | 0.0 |
| Till Grass | 0.0 | 0.0 | 2.0 | 2.0 | 0.0 | 0.0 | 0.0 |
| Outwash/Ice Contact Forest | 0.0 | 0.0 | 2.0 | 2.0 | 0.0 | 0.0 | 0.0 |
| Outwash/Ice Contact Pasture | 0.0 | 0.0 | 2.0 | 2.0 | 0.0 | 0.0 | 0.0 |
| Outwash/Ice Contact Grass | 0.0 | 0.0 | 2.0 | 2.0 | 0.0 | 0.0 | 0.0 |
| Wetland | 0.0 | 0.7 | 10.0 | 2.0 | 0.0 | 0.0 | 0.7 |
| Groundwater Aquifer | 0.0 | 0.0 | 2.0 | 2.0 | 0.0 | 0.0 | 0.0 |

| Pervious Land Type | CEPSC | UZSN | NSUR | INTFW | IRC | LZETP |
|---|---|---|---|---|---|---|
| Till Forest | 0.20 | 0.50 | 0.35 | 6.00 | 0.85 | 0.70 |
| Till Pasture | 0.10 | 0.25 | 0.25 | 6.00 | 0.85 | 0.25 |
| Till Grass | 0.15 | 0.40 | 0.30 | 6.00 | 0.85 | 0.40 |
| Outwash/Ice Contact Forest | 0.20 | 0.50 | 0.35 | 0.00 | 0.70 | 0.70 |
| Outwash/Ice Contact Pasture | 0.10 | 0.50 | 0.25 | 0.00 | 0.70 | 0.25 |
| Outwash/Ice Contact Grass | 0.15 | 0.50 | 0.30 | 0.00 | 0.70 | 0.40 |
| Wetland | 0.10 | 3.00 | 0.50 | 1.00 | 0.85 | 0.80 |
| Groundwater Aquifer | 0.20 | 0.50 | 0.35 | 0.00 | 0.70 | 0.80 |

**Table 5b – Calibrated HSPF Parameter Set for Impervious Areas**

| Cover Type | LSUR | SLSUR | NSUR | RETSC |
|---|---|---|---|---|
| Impervious | 500 | 0.01 | 0.1 | 0.1 |

See Ref 1 for an explanation of the HSPF parameters and their application in the model.

## CONCLUSIONS

Analyses were conducted using the HSPF hydrologic model to examine and characterize the hydrology of the Rock Creek watershed and the effects of water supply withdrawals at the City of Kent's, Clark Springs Water Supply System.

Three separate periods were used to calibrate the HSPF model, which included different rates of withdrawal and flow augmentation. The first period included natural flow conditions (essentially no withdrawals), the second included the largest withdrawal rates, the third moderate withdrawals with augmentation during an unusually dry autumn period.

Overall, the model calibration results show close agreement between simulated and recorded streamflow for the more than 32-years of data used in the calibration indicating that the model accurately simulates Rock Creek streamflow for a variety of climatic, withdrawal, and streamflow augmentation conditions. The HSPF model simulated the low-flow conditions well within the range of observed historical conditions. However, it becomes increasingly uncertain to estimate low-flows for conditions more severe than the observed record.

Thus, the model is valid as a tool for examining the effects of water withdrawal and augmentation scenarios on streamflow. Results of various water supply withdrawal and augmentation simulation scenarios will be presented in a subsequent report.

## REFERENCES


1. US Environmental Protection Agency, Hydrological Simulation Program-Fortran, Release 11, EPA/600/R-97/030, August 1997.

2. King County Department of Public Works, Surface Water Management Division, Cedar River Current and Future Conditions Report, November 1993.

3. Barker BL, Hydrologic Analysis of City of Kent Clark Springs Water Supply Operations in the Rock Creek Catchment Using the HSPF Model, prepared for the City of Kent Department of Public Works, MGS Engineering Consultants, Inc., November 2002.

4. Barker BL, Hydrologic Analysis of City of Kent Clark Springs Water Supply Operations in the Rock Creek Catchment Using the HSPF Model – Supplemental Analyses, prepared for the City of Kent Department of Public Works, MGS Engineering Consultants, Inc., July 2003

5. McDonald A.G. and M.W. Harbaugh, 1988. A Modular Three-Dimensional Finite-Difference Groundwater Flow Model. Techniques of Water Resources Investigations, Book 6, Chapter A1. USGS, Reston, Virginia.

6. Hart Crowser, Rock Creek Catchment Groundwater Flow Model, prepared for the City of Kent Department of Public Works, March 13, 2003.

7. Hart Crowser, The Hydrogeology of Rock Creek Kent, Washington, prepared for the City of Kent Department of Public Works, May 2003.

8. Sutherland, Roger, C., Methodology for Estimating the Effective Impervious Area of Urban Watersheds, Technical Note 58, Watershed Protection Techniques, Vol 2, No 1, Fall 1995.

9. Oregon Climate Service, Mean Annual Precipitation Maps for Western United States, PRISM Model, Corvallis Oregon, 1997.

10. Schaefer MG and Barker BL, Extended Precipitation Time-Series for Continuous Hydrological Model in Western Washington, prepared for Washington Department of Transportation, MGS Engineering Consultants, Inc., 2002

11. Schaefer MG, Barker BL, Wallis JR and Nelson RD, Creation of Extended Precipitation Time-Series for Continuous Hydrological Modeling in Pierce County Washington, for Pierce County Public Works Department, MGS Engineering Consultants, Inc, Entranco, and Dr. JR Wallis, February 2001.

12. Hart Crowser, Hydrologic Effect of Withdrawal Curtailment at Clark Springs, Memorandum from Michael Kenrick to Bill Wolinski, August 20, 2004.

# APPENDIX F

## PHABSIM / HSPF Linked Operations Analysis Tool

*Prepared by:*

Alan Olson
Dudley Reiser

R2 Resource Consultants, Inc.
15250 NE 95th Street
Redmond, WA 98052

January 24, 2006

*This page intentionally left blank.*

# PHABSIM / HSPF Linked Operations Analysis Tool

## INTRODUCTION

The City of Kent obtains as much as 60 percent of its water supply from Clark Springs, located in the Rock Creek watershed. The City of Kent owns approximately 320 acres of land surrounding Clark Springs. Most of the 7.4 mile length of Rock Creek is intermittent and/or ephemeral. The perennial portion of the creek begins at approximately RM 2.8, near the stream crossing at 262 Ave SE, which is upstream of the eastern extent of the City of Kent's Clark Springs property (Figure 1). The City of Kent withdraws groundwater from the Rock Creek basin for municipal water supply purposes on a year-round basis. These groundwater withdrawals, at a minimum, result in a reduction in the level of surface flows in Rock Creek during some portions of the year (Hart Crowser 2003a; Hart Crowser 2003b, MGS Engineering 2005). It is widely accepted that changes in surface flows can also result in changes in the amount of fish habitat in a stream (Milhous et al. 1984; WDFW and WADOE 2003).

The Physical Habitat Simulation (PHABSIM) System is a modeling approach developed by the Instream Flow Group of the U.S. Fish and Wildlife Service (USFWS) that relates fish habitat to water flow levels (Milhous et al. 1984). An operations analysis tool that combines the output from the Hydrologic Simulation Program Fortran (HSPF) model (MGS Engineering 2005) and the PHABSIM system was chosen as the method for assessing the effects of the City of Kent's withdrawals on fish habitat and as a tool for comparing the potential effects of alternative flow mitigation measures. The PHABSIM system is based upon species and lifestage specific utilization of three habitat features: water depth, water velocity, and substrate type. It utilizes three models: the Water Surface Profile Program (WSP), the Q-V (Flow-Velocity) Hydraulic Simulation Program (IFG-4), and Physical Habitat (HABTAT) model. WSP provides detailed information on depth and transverse velocity across a stream cross-section. It predicts the horizontal distribution of depth and mean column velocity over a range of streamflows with one set of field data. The IFG-4 model develops the depth and velocity data required by the HABTAT program. The HABTAT program utilizes the species and life stage specific habitat suitability curves. Output from the model provides an index of the amount of suitable habitat, called the weighted useable area (WUA) that is provided at different flows. The units for WUA are usually reported in square feet per 1000 feet of stream length, but may also be reported as the total WUA for a given stream reach.

The PHABSIM/HSPF Linked Operations Analysis Tool (PHLOAT) utilizes the daily mean flow output from the HSPF model to calculate flow statistics. A variety of flow scenarios were run in the HSPF model including baseline (existing) conditions, no-withdrawal conditions, and flow augmentation conditions proposed by the City of Kent as part of the HCP. In turn, the simulated flow statistics allow the calculation of a WUA time series for each species and lifestage of interest under each flow scenario. An overview of the PHABSIM/HSPF operations analysis tool is depicted in Figure 2.

## METHODS

The PHABSIM system requires depth, mean column velocity, and substrate data along cross-sectional transects representative of the habitats found in the stream. Depth and velocity data were collected at three flow levels to use in the calibration of hydraulic models. Transects were located at 6 sites between RM 0.2 and RM 2.0 (Figure 1). PHABSIM site information is provided in Table 1. Data for Sites 1, 2, and 3 were collected during late 2001 and early 2002. A review of the sites during the spring of 2004 suggested that the sites were representative of run type habitats present within the Clark Springs watershed boundary and riffle and run habitat within the Rock Creek Natural Area (Table 2). However, it was determined that supplemental sites would be needed to represent pool habitat and to ensure the presence of one site downstream of the City of Seattle's water pipeline, reaches that are heavily utilized by spawning sockeye salmon and have the highest likelihood of utilization by spawning Chinook salmon. The supplemental sites (A, B, and C) were selected to include one pool, one run (pool tail-out), and one riffle habitat type.

As indicated earlier, WUA-flow relationships were developed for specific species and life-history stages of concern. These species and life-history stages were:

- Chinook salmon spawning, fry, and juvenile;
- Sockeye salmon spawning;
- Coho salmon spawning and juvenile;
- Cutthroat spawning, juvenile, and adult;
- Bull trout spawning, juvenile, and adult;
- Steelhead spawning, juvenile;
- Rainbow trout spawning, juvenile, over-wintering, and adult.

Table 3 describes the source of habitat suitability curves utilized in the analysis. The Washington Department of Fish and Wildlife (WDFW) and Department of Ecology (WDOE) have developed a set of recommended habitat suitability curves, known as the "Fallback curves," for use when stream-specific suitability curves are not available, as is the

situation for Rock Creek (WDFW and WDOE, 2003). Two alternative WUA-flow relationships were developed for Chinook spawning based upon different habitat suitability curves. One WUA-flow curve is based upon the WDFW and WDOE (2003) Fallback curves. However, Caldwell, et al. (1990), the source for the WDFW and WDOE (2003) Fallback curves, note that the depth and velocity curves were based upon curves from the Yakima and Sandy rivers, which are much larger than Rock Creek, that were adjusted to have a higher suitability for lower velocities and depths using professional judgment. In contrast, the depth and velocity curves known as the "Douglas" curves are based upon unpublished data collected by R2 Resource Consultants at a number of smaller streams closer in size to Rock Creek. A comparison (Figure 3) of the curves indicates a higher suitability for lower velocities and shallower depths and lower suitability for higher velocities under the Douglas curves relative to the Fallback curves. For completeness, both sets of curves were used in the analysis.

The Conservation Plan for WRIA 8 (WRIA 8 Steering Committee 2005) considers Chinook fry and their associated habitat to be a critical life stage in the Cedar River and its' tributaries that provide suitable spawning habitat. However, WDFW and WDOE (2003) do not include habitat suitability curves for Chinook fry. Consequently, fry suitability curves for depth and velocity were modified from a recently completed PHABSIM study in the Snake River Basin of Idaho (R2 unpublished data). In that study, suitability curves were established following an exhaustive review of available suitability curves and discussions with experts in Chinook biology, instream flow studies, and PHABSIM studies in particular. All substrates and all depths over 0.7 feet were considered suitable for fry because the relatively narrow water velocity suitability was considered the key factor driving habitat suitability. These suitability curves are provided in Figure 4.

The PHABSIM system allows for the calculation of a species and life-stage specific WUA versus flow relationship for each transect or for each site, which is a composite of each transect within the site. In addition, composite WUA versus flow curves were developed by habitat type (run, riffle, pool; Table 2). The result is a single WUA versus flow curve that represents the entire amount of habitat for a species and life history stage in a stream segment of interest. With this approach, each WUA versus flow curve is weighted by the proportion of stream habitat the transect represents. For example, Site B Transect 3 represented 20 feet of a pool and the total pool habitat represented by transects was 111.9 feet. Consequently, the WUA versus flow curve from this transect had a weight of 0.18.

To complete the composite WUA versus flow curve, the proportion of each habitat type in the stream segment of interest was used to weight each composite habitat WUA versus flow

curve. A number of fish habitat surveys have been conducted in Rock Creek (Jones and Stokes 1993; May 1996; Pentec 2001). However, only summary data that were not suitable for the current analysis were available. Consequently, a habitat survey was conducted by R2 on November 9 and November 10, 2004 when Rock Creek flow levels were approximately 5.0 cfs at the mouth of Rock Creek and approximately 3.9 cfs at the flume near Kent-Kangley Road. Table 4 presents the results of this survey by stream reach. Cascades were a rare habitat and accounted for only about 1.5 percent of the stream length. Consequently, the cascade habitat lengths were combined with the riffle habitat type. The augmentation pipe voluntarily utilized by the City of Kent during low flow periods is located at the break between Reach 9b and Reach 10. Because flow mitigation scenarios are an important part of the operations analysis for the HCP, those portions of Rock Creek downstream of the augmentation pipe were considered the most critical for the analysis. Furthermore, operation tests have demonstrated that the effect of withdrawals declines rapidly within about 1000 feet upstream of the infiltration gallery (Hart Crowser 2003a).

The July 2004 operations test also suggested that augmentation flow losses would occur if augmentation occurred near the clear well. During the test approximately 2.0 cfs was augmented, but the increase in surface flow at the flume was 1.4 cfs, suggesting approximately 30 percent of the augmentation flow was lost to groundwater prior to reaching the flume. An additional test during September 2005 and examination of historical data suggests that the amount of loss is variable, but ranges between approximately 30 to 50 percent of the amount augmented. As a result of this finding, the City of Kent is planning to relocate the outlet of the augmentation pipe during 2006 to a location closer to the flume in order to minimize any losses to groundwater near the water supply facilities. Therefore, only Reaches 1 through the Parshall Flume (i.e., includes all but the upper 495 feet of Reach 9b) were considered when developing a composite WUA versus flow curve for each species and life history stage of interest. A total WUA versus flow curve was calculated by multiplying the composite curve (in square feet of WUA per 1000 feet of stream) by the length of stream (9,697 feet) divided by 1000.

Figures 5 and 6 provide total WUA versus flow curves for species and life history stages of interest. To provide context to the range of WUA depicted in Figures 5 and 6, the maximum amount of surface area of Reaches 1 through 9b using the average bankfull width (29.1 ft) is 2821,183 $ft^2$. While the WUA versus flow curves were generated for flows up to 50 cfs, some life stages for species of interest may rarely or ever experience flows over some portion of the curve during periods when they are present in Rock Creek. For example, Chinook salmon spawning in the Cedar River is generally completed by the end of November. However, based upon the results of HSPF modeling, flows greater than 10 cfs in

Rock Creek would be rare prior to November 12, and then with a probability of only 1 in 5 years even if there were no water withdrawals at Clark Springs.

## INCORPORATING HSPF MODELING INTO THE TOOL

As described in MGS Engineering (2005), the HSPF model allows the simulation of mean daily stream flows over a 45-year period under different operational scenarios that include current baseline operations using mean monthly withdrawal rates, no withdrawals, and a scenario consistent with Kent's flow mitigation proposal (i.e., 3 cfs as a minimum flow target during October, November, and December that utilizes flow augmentation as needed to meet the target). Exceedance flow values for these three scenarios are provided in Figure 7. Using the total WUA versus flow curves, a daily WUA value can be calculated from the simulated daily flow, which in turn allow the calculation of habitat duration (exceedance) curves on a monthly basis for each species and life history stage of interest. Knowledge of the periodicity for the different life stages (Table 5) was used to focus the analysis on critical months. For species with life history stages that may be found in Rock Creek throughout the year, four representative months (October, January, April, and July) were chosen for reporting purposes.

## RESULTS

The following describes the results of the analysis under three scenarios: no withdrawals, mean monthly historical withdrawals, and the City of Kent's proposed flow augmentation program that targets a 3 cfs minimum flow (provided by up to 2 cfs of flow augmentation) during October, November, and December. Results are presented by species.

### CHINOOK

Chinook salmon spawning for the Cedar River system primarily occurs during the months of October and November. Chinook salmon fry typically begin emergence from the gravel as soon as late January. Chinook fry have generally completed outmigration from the Cedar River by early June.

The historic distribution of Chinook salmon in Rock Creek is uncertain. Different sources (primarily GIS-based) have placed the upper extent of Chinook spawning at RM 1.3, RM 0.65, RM 0.27, and RM 0.20. Documented rationale for these locations is limited (WDFW and WWTIT 1994, SSHIAP 2005, Streamnet 2005, and WRIA 8 Steering Committee 2005). The latter two locations are in the approximate locations of the SE 248th Street culvert and

the Seattle Pipeline culverts. Both culverts have been cited as partial barriers to anadromous fish (Chinook Engineering 2002; King County et al. 1999). Neither of the culverts are considered complete barriers to adult salmon, but instead are cited as partial barriers at some flow levels. However, the SE 248th Street culvert has been recently replaced. The RM 1.3 location was based upon the upper extent of the WDFW spawning survey index reach (Summit-Landsburg Road; primarily for coho) and not necessarily observations of Chinook salmon at that location. RM 0.65 was the extent examined using the EDT model in the WRIA 8 Conservation Plan. A GIS-based analysis of Chinook spawning habitat in WRIA 8 suggested that potential use of Rock Creek by Chinook salmon was very unlikely because Rock Creek was too small (NOAA Fisheries 2005, personal communication).

Habitat duration curves for two Chinook salmon life stages, two alternative spawning HSI curves, and four alternative distributions were modeled. These were spawning and fry through Reach 3 (RM 0.28), Reach 5 (RM 0.67), Reach 8 (RM 1.58), and Reach 9b (RM 1.85). The end of Reach 8 was chosen as the end of one alternative distribution because RM 1.3 occurs in the middle of Reach 8. The WDFW index reach ends at Summit-Landsburg Road (Steve Foley, personal communication), which is an obvious access location, and we assumed that river mile discrepancies resulted from different measuring methods (e.g., GIS versus a topographic map and map-wheel). As described earlier, spawning HSI curves included the Washington State Fallback curves and the Douglas curves. Habitat duration curves for these life stages through Reach 9b are presented in Figure 8.

The PHLOAT suggests that under current operations the median amount of Chinook salmon spawning habitat through Reach 9b is approximately 168 $ft^2$ of WUA during October and 47 $ft^2$ of WUA during November using the Washington State fallback HSI curves (Table 6). Under the Douglas HSI curves, which are believed to be more appropriate for small streams, the median amount of Chinook spawning habitat is approximately 2,977 $ft^2$ of WUA during October and 1,756 $ft^2$ during November. Under the proposed flow mitigation, Chinook salmon spawning habitat would increase to 1,307 $ft^2$ during October and November using the Fallback curves and 9,139 $ft^2$ using the Douglas curves. These represent a 7.8 to 27.7-fold increase over Baseline Conditions using the Fallback curves and 3.1 to 5.2-fold increase using the Douglas curves.

An analogous analysis for the alternative Chinook distributions indicates the primary difference is scalar (i.e., the shorter alternative reach lengths have less total WUA) (Table 7, Figure 9). Under the proposed flow mitigation the amount of total WUA would increase on a proportional basis in a similar fashion for each alternative distribution. Compared to Baseline conditions, under the fallback curve the proposed flow mitigation would increase

total WUA 7.8 to 8.2-fold during October and 27.7 to 30.8-fold during November depending upon the distribution. Under the Douglas curve, the WUA increase would be 2.9 to 3.1-fold during October and 4.7 to 5.2-fold during November.

The analysis also illustrates how differences between the Douglas and fallback HSI curves may affect the potential availability of spawning habitat in different reaches. With the Douglas curves, under Baseline conditions over 40 percent of the total WUA downstream of the Parshall Flume is accounted for in Reaches 1 through 5 (to RM 0.67) compared to approximately 21 percent under the Fallback curves. In contrast, under the Fallback curves Reaches 9 and 9b (up to the Parshall Flume) account for a relatively high proportion (approximately 31%) of the total WUA downstream of the augmentation pipe compared to approximately 13 percent under the Douglas curves. This difference results primarily from the fact that the Fallback curves have a deeper optimal depth range compared to the Douglas curves and consequently reaches with a higher proportion of pool habitat are modeled as having more Chinook spawning habitat. These distinctions are important because there is a higher likelihood of Chinook accessing and utilizing the lower reaches in Rock Creek because of its proximity to the Cedar River.

Under current operations, the PHLOAT suggests that under median conditions fry habitat ranges from approximately 67,024 $ft^2$ of WUA during May to about 75,739$ft^2$ of WUA during February (Figure 10). These amounts represent 91.3 (May) to 99.6 (February) percent of the available habitat under the no-withdrawal scenario. Consequently, the analysis tool suggests that withdrawals under the current project operations and the proposed HCP have a relatively small effect on fry habitat. The proposed minimum flows during October, November, and December will not affect Chinook fry because they are not present during that time period.

During the month of March the median amount of Chinook fry WUA was 9,243 $ft^2$ in Reaches 1 through 3, while Reaches 4 and 5 accounted for 12,192 $ft^2$, Reaches 6 through 8 accounted for 37,118 $ft^2$, and Reaches 9 and 9b up to the Parshall Flume accounted for 16,166 $ft^2$ (Figure 11). The trends in WUA over time were similar among the different distributions with February having the highest median WUA and May having the lowest. Similar to spawning habitat under the fallback curve, the distribution of Chinook fry habitat WUA was disproportionate to stream length. Reach 1 through Reach 3 accounted for about 16 percent of the stream length, but about 12 percent of the total fry WUA downstream of the augmentation pipe. Similarly Reaches 4 and 5 accounted for about 22 percent of stream length and 16 percent of fry WUA. Reaches 6 through 8 accounted for about 50 percent of

the length and about 50 percent of the WUA. Reach 9 and 9b up to the Parshall flume accounted for about 14 percent of the stream length, but about 22 percent of the fry WUA.

## COHO SALMON

Coho salmon are present in Rock Creek throughout the year. Adult salmon may enter Rock Creek in late-October, but more generally the spawning migration begins in mid- to late-November with peak spawning from the second week in December through mid-January (R2 2003, 2004). Juvenile coho salmon may rear in Rock Creek for about a year, migrating as smolts during the spring following their emergence from the gravel. Some coho juveniles may also emigrate over the year and undergo smoltification within the Cedar River. The availability of coho salmon fry habitat is assumed to be similar to that of Chinook salmon fry.

The PHLOAT suggests that under Baseline conditions, the median amount of coho salmon spawning habitat is approximately 1,549 $ft^2$ of WUA during November and approximately 17,917 to 21,628 $ft^2$ of WUA during December to January (Figure 12). Under the proposed flow mitigation, the median amount of coho salmon habitat would increase to 1,868 $ft^2$ of WUA during November, but no changes would occur in the median amount of WUA during December through February. These represent a 2.2-fold increase over Baseline conditions during November. Only during years when flows are low (e.g., habitat duration value of 80% exceedance or greater), the proposed minimum flows during December would increase the amount of spawning habitat from approximately 1,549 $ft^2$ of WUA to about 3,417 $ft^2$ of WUA or about a 2.2-fold increase over Baseline conditions.

The amount of habitat for juvenile coho salmon is relatively stable throughout the year (Figure 13), regardless of the withdrawal scenario. The PHLOAT indicates that total habitat WUA would range between about 9,151 $ft^2$ under drought conditions and 9,988 $ft^2$ under wet conditions. During the high flow winter months, water supply withdrawals result in a small increase (e.g., about 281 $ft^2$ during January) in median coho juvenile habitat relative to the no withdrawals scenario. The flow mitigation proposal would provide a small increase (e.g., about 469 $ft^2$ during October) compared to the Baseline Conditions.

## SOCKEYE

Sockeye salmon spawn in Rock Creek from October through December (R2 2003, 2004). Sockeye salmon have been observed to spawn up through Reach 12 in the Clark Springs Watershed, however the majority of spawning occurs in Reaches 1 through 4. Similar to

Chinook salmon fry, emergence begins in late January and continues through May with the peak of the migration to the Cedar River and Lake Washington occurring during late March and early April. The availability of sockeye fry habitat in Rock Creek is assumed to be similar to that of Chinook salmon.

The PHLOAT suggests that under Baseline conditions the median amount of sockeye salmon spawning habitat during October is approximately 4,042 $ft^2$ of WUA, while November has approximately 2,561 $ft^2$, and December has approximately 52,333 $ft^2$ (Figure 14). Under the proposed flow mitigation, the median amount of sockeye salmon habitat would increase to about 12,012 $ft^2$ of WUA during October and November, but no changes would occur in the median amount of WUA during December. These represent a 3.0-fold increase over Baseline conditions during October and a 4.7-fold increase during November. Similar to coho, during years with low flow conditions (e.g., habitat duration value of 80% exceedance or greater), the proposed minimum flows during December would increase the amount of sockeye spawning habitat from approximately 2,561 $ft^2$ of WUA to about 12,012 $ft^2$ of WUA or about a 4.7-fold increase over Baseline Conditions.

### CHUM

The migration period of chum salmon spans a three-month period from October through December. Chum fry tend to outmigrate to estuarine areas shortly after emergence from the gravel (Salo 1991), so it is not expected that chum fry would extensively use Rock Creek for rearing if any successfully spawn in the creek.

The PHLOAT suggests that under baseline conditions the median amount of chum salmon spawning habitat during October is approximately 5,718 $ft^2$ of WUA, while November has approximately 4,985 $ft^2$, and December has approximately 41,657 $ft^2$. Under HCM-1, the median amount of chum salmon habitat would increase to 9,985 $ft^2$ of WUA during October and November, but no changes would occur in the median amount of WUA during December. These represent a 1.7-fold increase over baseline conditions during October and a 2.0-fold increase during November. During years with low flow conditions (e.g., habitat duration value of 80% exceedance or greater), the proposed minimum flows during December would increase the amount of chum spawning habitat from approximately 4,496 $ft^2$ of WUA to about 9,985 $ft^2$ of WUA or about a 2.2-fold increase over current conditions.

## STEELHEAD TROUT

Steelhead trout were historically present in Rock Creek, but the current level of utilization is uncertain. If steelhead trout utilize Rock Creek, the population level is likely to be relatively low. The distribution of steelhead trout would likely be similar to coho salmon; i.e., approximately near the eastern boundary of the Rock Creek Watershed (RM 2.75). Rainbow trout, the resident life history form of *O. mykiss*, is present throughout Rock Creek where suitable habitat is available. Steelhead trout in the Cedar River Watershed spawn from late-January through early-June. Juvenile rearing occurs throughout the year. The availability of steelhead trout fry habitat in Rock Creek is assumed to be similar to that of Chinook salmon.

Steelhead trout spawning habitat was modeled during April, May, and June using the PHLOAT. During this period the available amount of spawning habitat declines concurrently with declines in flow (Figure 15). Under Baseline conditions, PHLOAT estimated the median amount of WUA was 6,937 $ft^2$ for April, 3,015 $ft^2$ for May, and 823 $ft^2$ for June. The proposed flow mitigation is not expected to affect the amount of habitat available to spawning steelhead trout.

Similar to coho salmon, steelhead trout juvenile habitat is depicted graphically during four representative months over the year (October, January, April, and July). Under Baseline conditions, PHLOAT estimated the median amount of WUA was 715 $ft^2$ for October, 7,325 $ft^2$ for January, 5,375 $ft^2$ for April, and 1,651 $ft^2$ for June (Figure 16). During the proposed flow mitigation period a moderate increase over Baseline conditions is expected during October and November (e.g., an additional 613 $ft^2$ of WUA during October).

## BULL TROUT

There are no documented observations of bull trout utilizing Rock Creek. However, rare observations of bull trout have occurred in the Cedar River and bull trout are known to enter Lake Washington from nearshore areas through the Ballard Locks. In the upper Cedar River, bull trout spawn during October and November and rearing occurs year-round. The PHLOAT estimated the median amount of bull trout spawning WUA was 27,549 $ft^2$ during October and 24,825 $ft^2$ during November under Baseline conditions. Under the proposed flow mitigation spawning habitat would increase to 41,117 $ft^2$ of WUA during both October and November (Figure 17).

Similar to other salmonids that might reside year-round in Rock Creek, juvenile habitat is depicted graphically during four representative months over the year (October, January,

April, and July). Under Baseline conditions, PHLOAT estimated that the median amount of bull trout juvenile and adult WUA was 1,952 $ft^2$ for October, 18,597 $ft^2$ for January, 13,837 $ft^2$ for April, and 4,207 $ft^2$ for June (Figure 18). During the proposed flow mitigation period a moderate increase over Baseline conditions is expected during October and November (e.g., an additional 1,474 $ft^2$ of WUA during October).

## CUTTHROAT TROUT

Adfluvial and/or fluvial cutthroat trout are known to utilize Rock Creek. A portion of the cutthroat population in Rock Creek may be a resident form that does not migrate to the Cedar River or Lake Washington, but there is no documented evidence of both life history forms being present. Cutthroat trout spawn during January and February. Juvenile and adult cutthroat trout may be present in Rock Creek year-round. The PHLOAT estimated the median amount of cutthroat trout spawning WUA was 36,384 $ft^2$ during January and 37,132 $ft^2$ during February under Baseline conditions (Figure 19). The proposed flow mitigation is not expected to affect cutthroat trout spawning habitat. During the high flow winter months when cutthroat trout spawning occurs, water supply withdrawals result in a small increase (e.g., about 2,749 $ft^2$ during January and 4,508 $ft^2$ of WUA during February) in median cutthroat trout spawning habitat relative to the no withdrawals scenario.

Similar to other salmonids that might reside year-round in Rock Creek, juvenile habitat is depicted graphically during four representative months over the year (October, January, April, and July). Under Baseline conditions, PHLOAT estimated the median amount of cutthroat trout juvenile and adult WUA was 325 $ft^2$ for October, 3,722 $ft^2$ for January, 2,782 $ft^2$ for April, and 920 $ft^2$ for June (Figure 20). During the proposed flow mitigation period the available habitat is expected to more than double over what would be provided under Baseline conditions during October and November (e.g., an additional 403 $ft^2$ of WUA during October).

## RAINBOW TROUT

Resident rainbow trout are present in Rock Creek year-round. Spawning occurs during late-February to early-June. Rainbow trout spawning habitat was modeled during February, March, April, and May using PHLOAT. During this period the available amount of spawning habitat declines concurrently with declines in flow. Under Baseline conditions, PHLOAT estimated the median amount of WUA was 34,254 $ft^2$ for February, 30,474 $ft^2$ for March, 25,885 $ft^2$ for April, and 17,148 $ft^2$ for May (Figure 21). The proposed flow

mitigation is not expected to affect the amount of habitat available to spawning rainbow trout.

Similar to other salmonids that might reside year-round in Rock Creek, rainbow trout juvenile habitat is depicted graphically during four representative months over the year (October, January, April, and July). Under Baseline conditions, PHLOAT estimated the median amount of WUA was 598 $ft^2$ for October, 4,705 $ft^2$ for January, 3,620 $ft^2$ for April, and 1,308 $ft^2$ for June (Figure 22). During the proposed flow mitigation period, an additional 479 $ft^2$ of WUA over Baseline conditions would occur during October.

Overwintering habitat was also modeled for rainbow trout during the months of December through March. The amount of overwintering habitat estimated by PHLOAT during this period ranged from 20,297 $ft^2$ to 22,886 $ft^2$ under Baseline conditions (Figure 23). During the high flow months of January, February, and March, water supply withdrawals result in a small increase (e.g., about 994 to 1,660 $ft^2$ of WUA) in median rainbow trout overwintering habitat relative to the no withdrawals scenario.

# REFERENCES

Caldwell, J, K. Bruya and B. Caldwell. 1990. Documentation and rationale for preference curves for IFIM studies. Draft. Washington State Dept. of Fisheries Habitat Management. 24 p.

Chinook Engineering. 2002. Fish Passage Analysis of the Seattle Public Utilities Lake Youngs Aqueduct Culvert Crossing of Rock Creek Near Maple Valley, WA. Report to Seattle Public Utilities.

Hart Crowser. 2003a. The Hydrogeology of Rock Creek Kent Washington. Report to City of Kent.

Hart Crowser. 2003b. Rock Creek Basin Groundwater Flow Model. City of Kent, Washington.

Jones & Stokes Associates, Inc. 1993. Technical Appendix E, Wilderness Retreat/Wilderness 50 Stream Survey in King County. Proposed Plat of Wilderness Retreat (S89p0140) and Proposed Plat of Wilderness 50 (S90POO72) Environmental Impact Statement. Bellevue, Washington.

King County, Sheldon & Associates, and The Watershed Company. 1999. Culvert Replacement and Bank Stabilization on Rock Creek in Vicinity of Southeast 248 Street (CC8491). Prepared for King County Department of Transportation, Road Services Division, Seattle, Washington.

May, C.W. 1996. Assessment of cumulative effects of urbanization on small streams in the Puget Sound lowland ecoregion: Implications for salmonid resource management. Ph.D. Dissertation, Department of Civil Engineering, University of Washington, Seattle, Washington. 384 p.

MGS Engineering. 2005. Hydrologic Analysis of City of Kent Clark Springs Water Supply Operations in the Rock Creek Catchment Using the HSPF Model Second Supplemental Analyses. Final Report to City of Kent.

Milhous, R.T., D.L. Wegner, and T. Waddle. 1984. User's guide to the Physical Habitat Simulation System (PHABSIM). Instream Flow Information Paper 11. U.S. Department of

Interior, Fish and Wildlife Service, Office of Biological Services, FWS/OBS-81/43 Revised, Washington, D.C.

NOAA Fisheries. 2005. Personal Communication between J. Davies (NOAA Fisheries) and A. Olson (R2 Resource Consultants). January 1.

Pentec. 2001. Rock Creek Fish Habitat Survey. Memorandum to T. Mortimer.

SSHIAPP. 2005. Salmon and Steelhead Habitat Inventory and Assessment Project. Downloaded from WDFWs SalmonScape Site. https://fortress.wa.gov/dfw/salmonscape/.

Streamnet. 2005. Online data query from www.streamnet.org.

WDFW and WDOE (Washington Department of Fish and Wildlife; Washington Department of Ecology). 2003. INSTREAM FLOW STUDY GUIDELINES: Technical and Habitat Suitability Issues DRAFT, June 2003. Draft Report from the Washington Department of Fish and Wildlife and Washington Department of Ecology.

WDFW and WWTIT (Washington Department of Fish and Wildlife and Western Washington Treaty Indian Tribes). 1994. 1992 Washington State Salmon and Steelhead Stock Inventory. Appendix One: Puget Sound stocks, south Puget Sound volume. Olympia: WDFW and WWTIT.

WRIA 8 Steering Committee. 2005. Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Chinook Salmon Conservation Plan. WRIA 8 Steering Committee.

# FIGURES AND TABLES

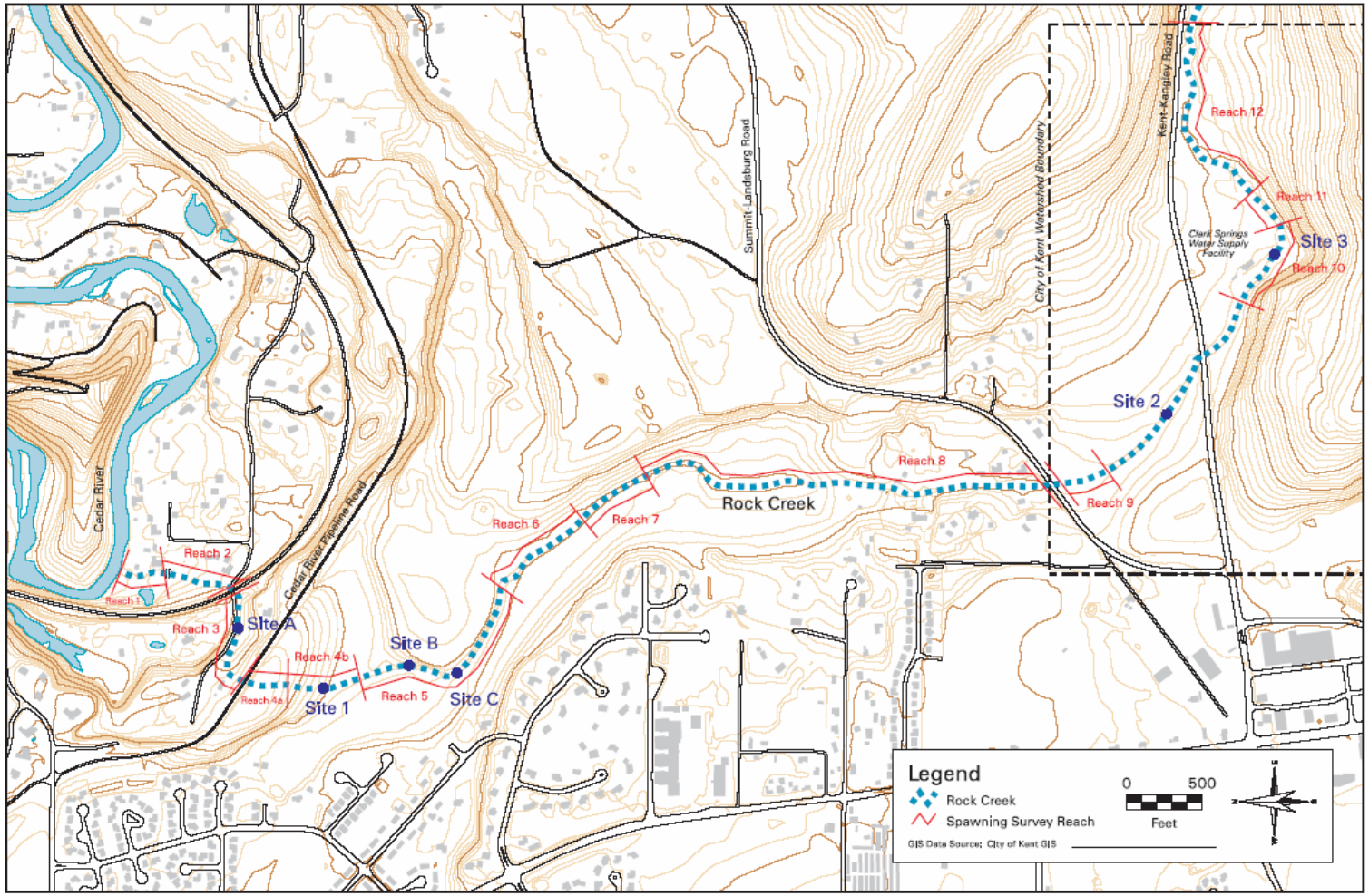



Figure 1. Map Rock Creek from its confluence with the Cedar River through the City of Kent Watershed at Clark Springs.

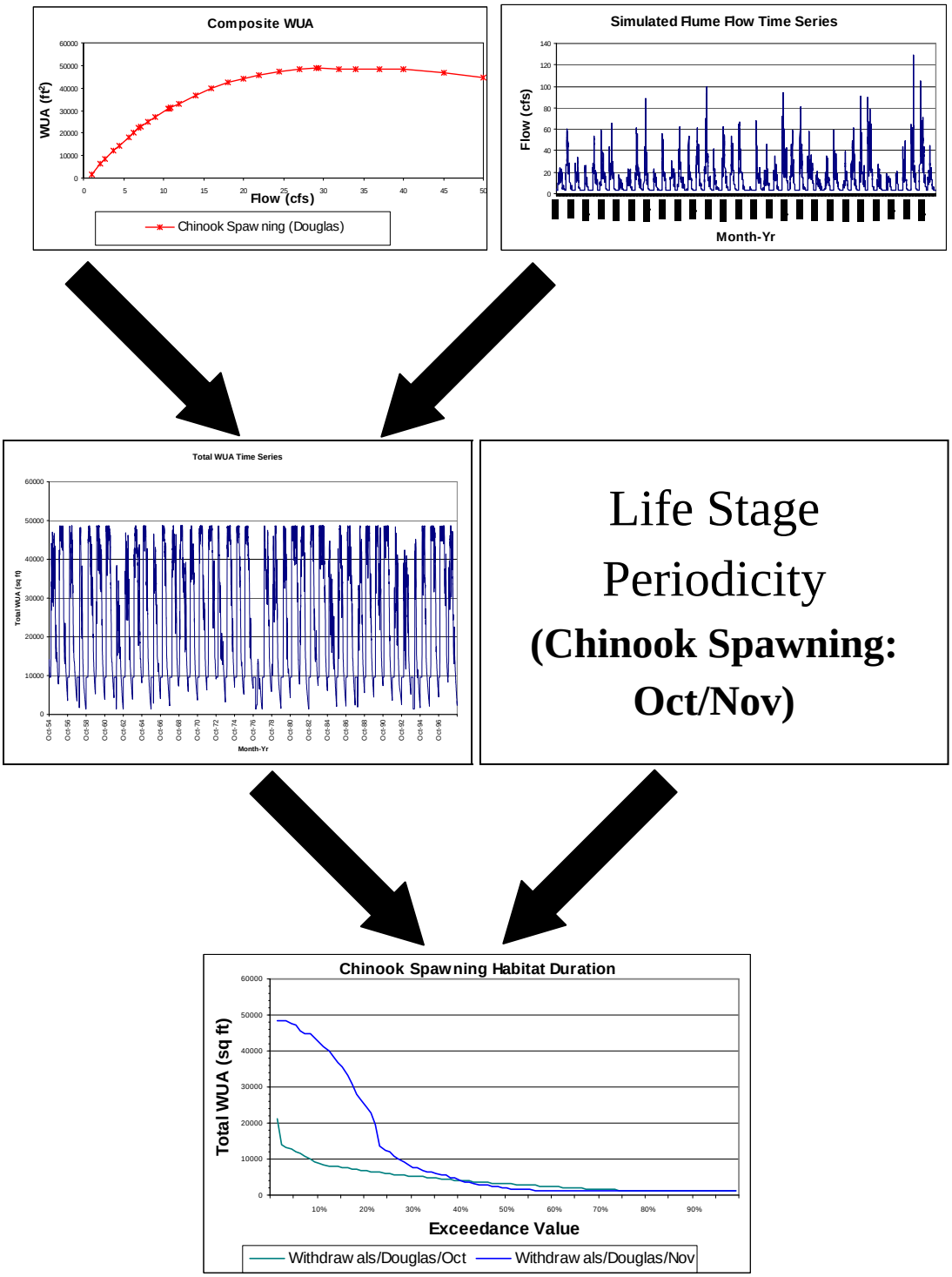
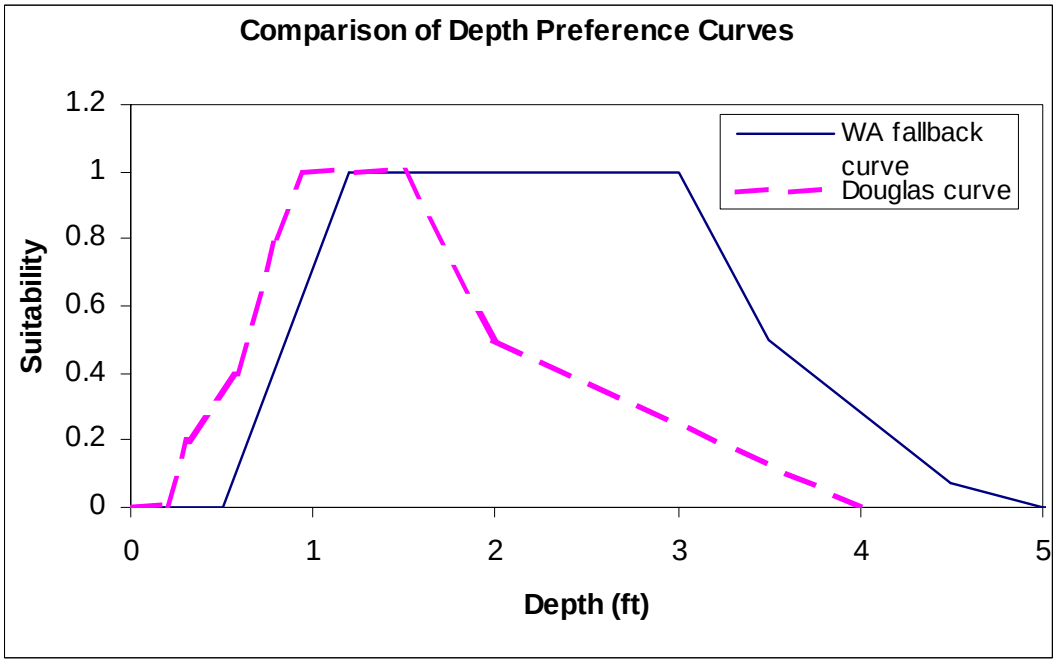



Figure 2. Overview of the PHABSIM/HSPF Linked Operations Modeling tool.



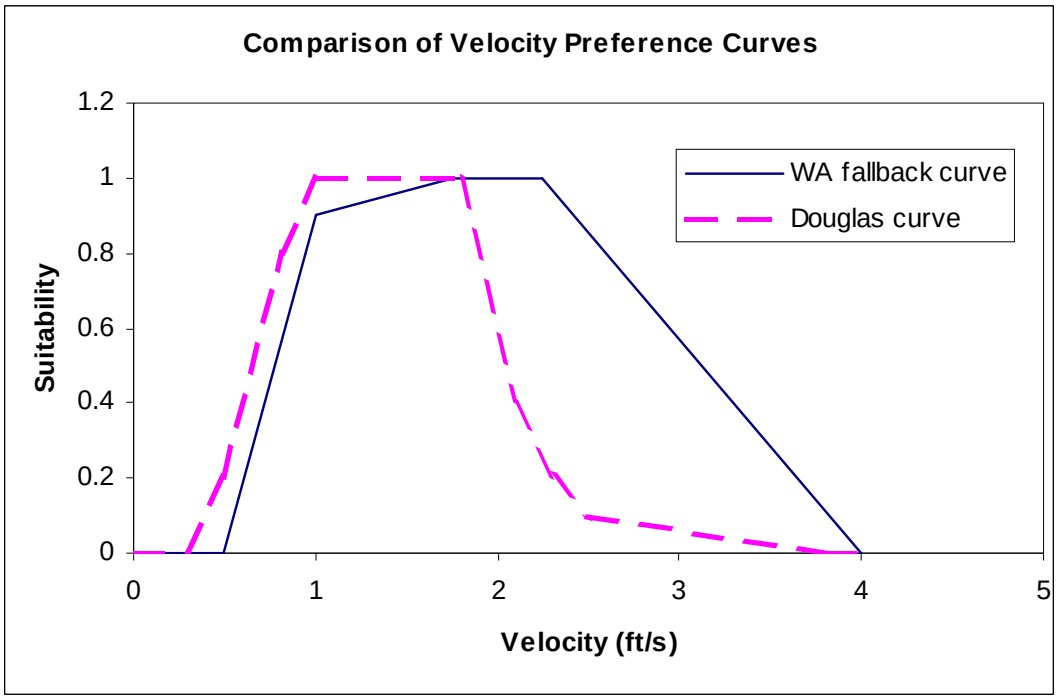
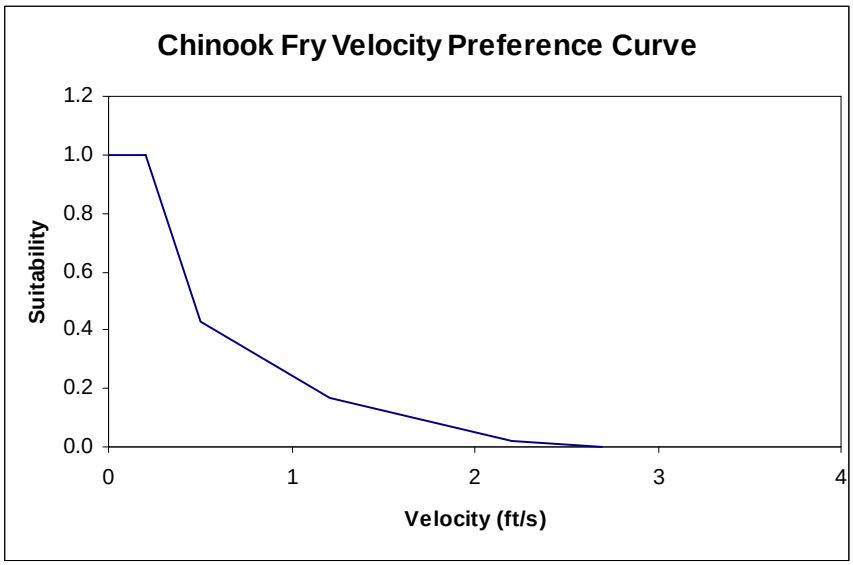




Figure 3. Comparison of the Washington Fallback and Douglas County Habitat Chinook Suitability Curves for Depth and Velocity.

| Velocity Preference | |
|---|---|
| **Velocity** | **Suitability** |
| 0.00 | 1.00 |
| 0.20 | 1.00 |
| 0.50 | 0.43 |
| 1.21 | 0.17 |
| 2.20 | 0.02 |
| 2.70 | 0.00 |




| Depth Preference | |
|---|---|
| **Depth** | **Suitability** |
| 0.00 | 0.00 |
| 0.10 | 0.00 |
| 0.70 | 1.00 |
| 3.00 | 1.00 |
| 3.50 | 1.00 |
| 4.50 | 1.00 |
| 5.00 | 1.00 |

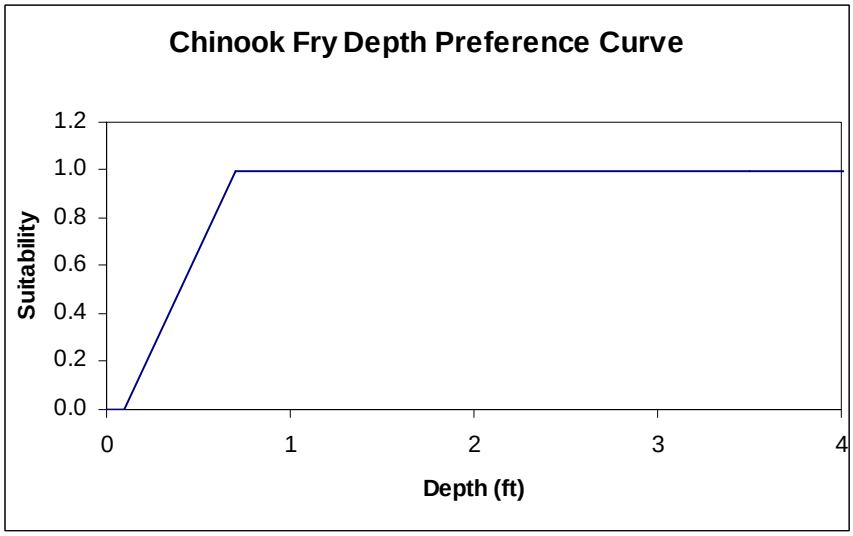



Figure 4. Chinook fry velocity and depth preference curves derived from the Snake River Basin Adjudication project (R2, unpublished). The source of the velocity curve is Beak Consultants (1985) from Oregon. The source of the ascending limb of the depth curve is Raleigh et al. (1986).

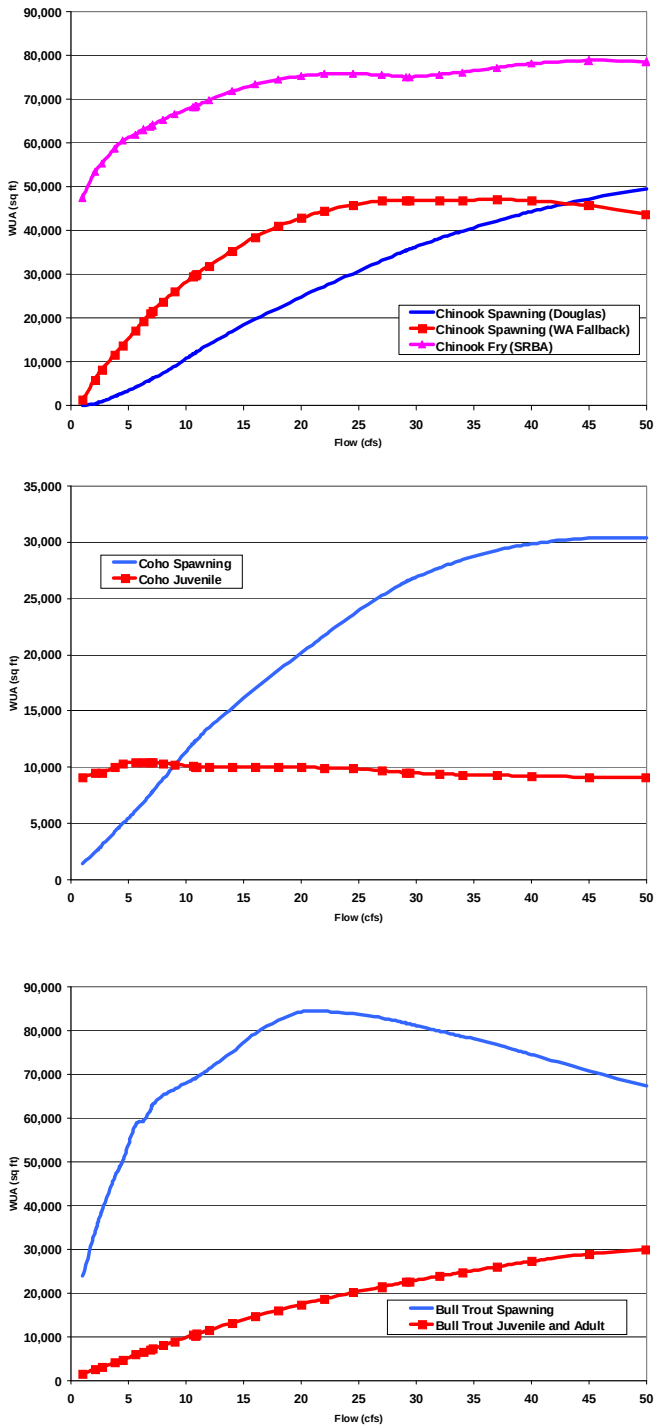



Figure 5. Total weighted useable area versus flow in Reaches 1 through 9b of Rock Creek for Chinook salmon (top), coho salmon (middle), and bull trout (bottom).

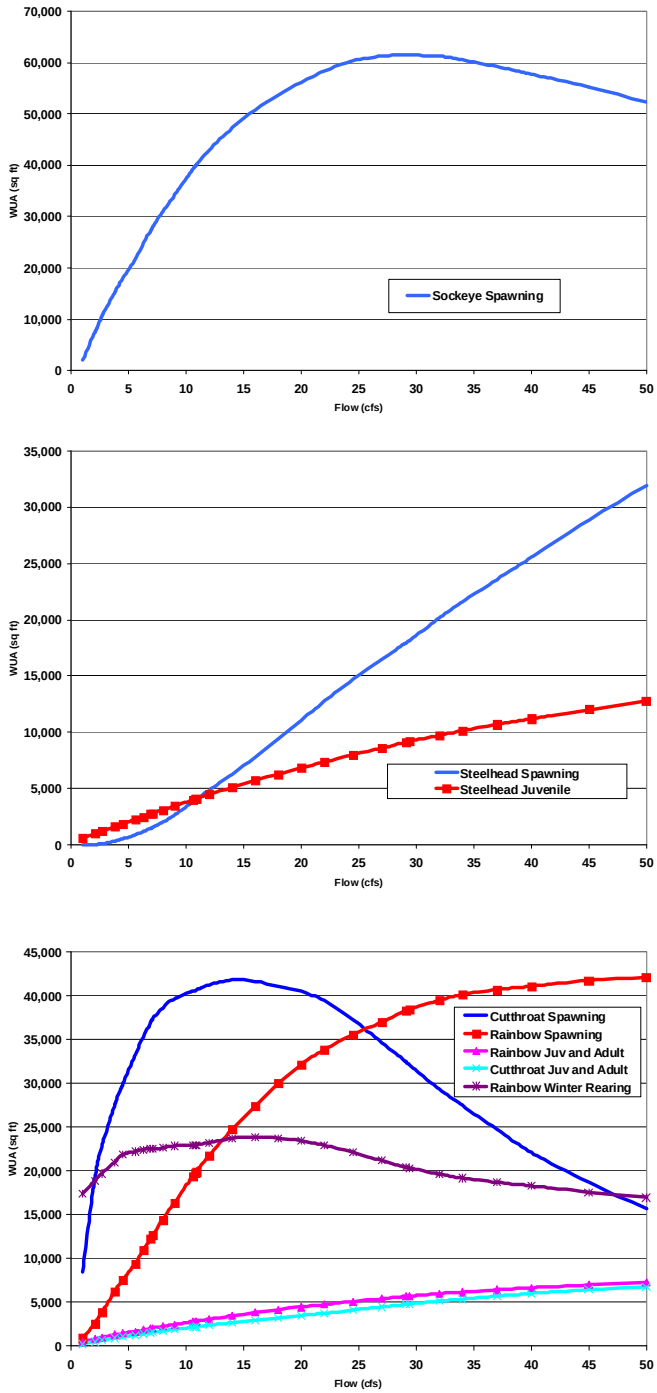



Figure 6. Total weighted useable area versus flow in Reaches 1 through 9b of Rock Creek for sockeye salmon (top), Steelhead trout (middle), and rainbow and cutthroat trout (bottom).

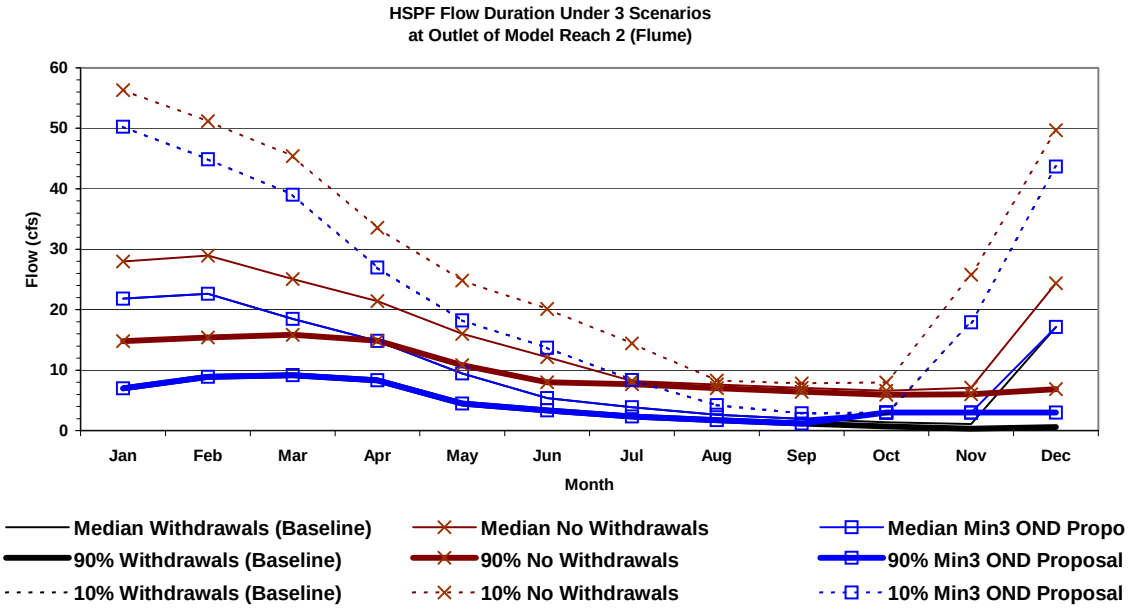



Figure 7. Median (50%), 10%, and 90% exceedance flow values at the outlet of model Reach 2 (Flume) from the HSPF model. "Min3 OND" indicates minimum 3 cfs flows during October November and December. The Min3 OND lines are identical to the Baseline scenario except during those months.

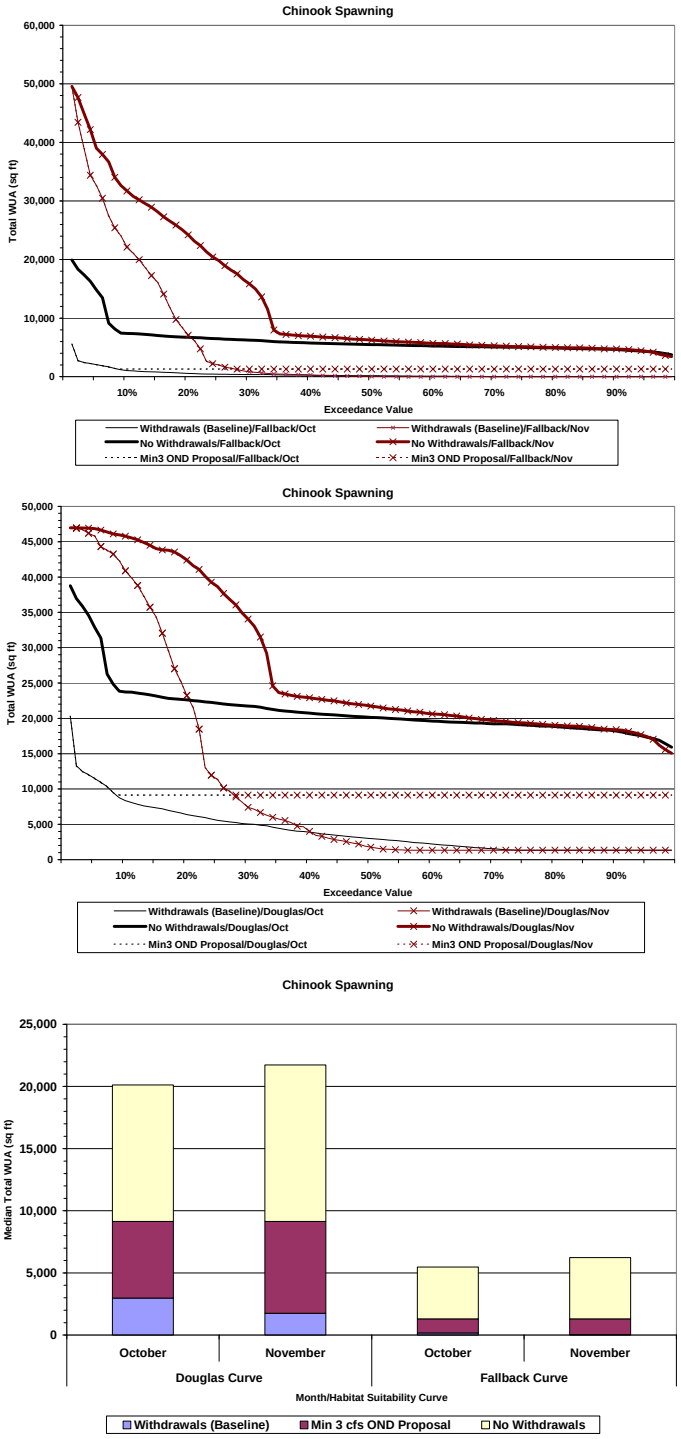



Figure 8. Habitat duration curves for Chinook salmon spawning Reach 1 to Reach 9b downstream of the Parshall Flume under the state Fallback curves (top) Douglas curves (middle). The lower graph depicts median habitat amounts.

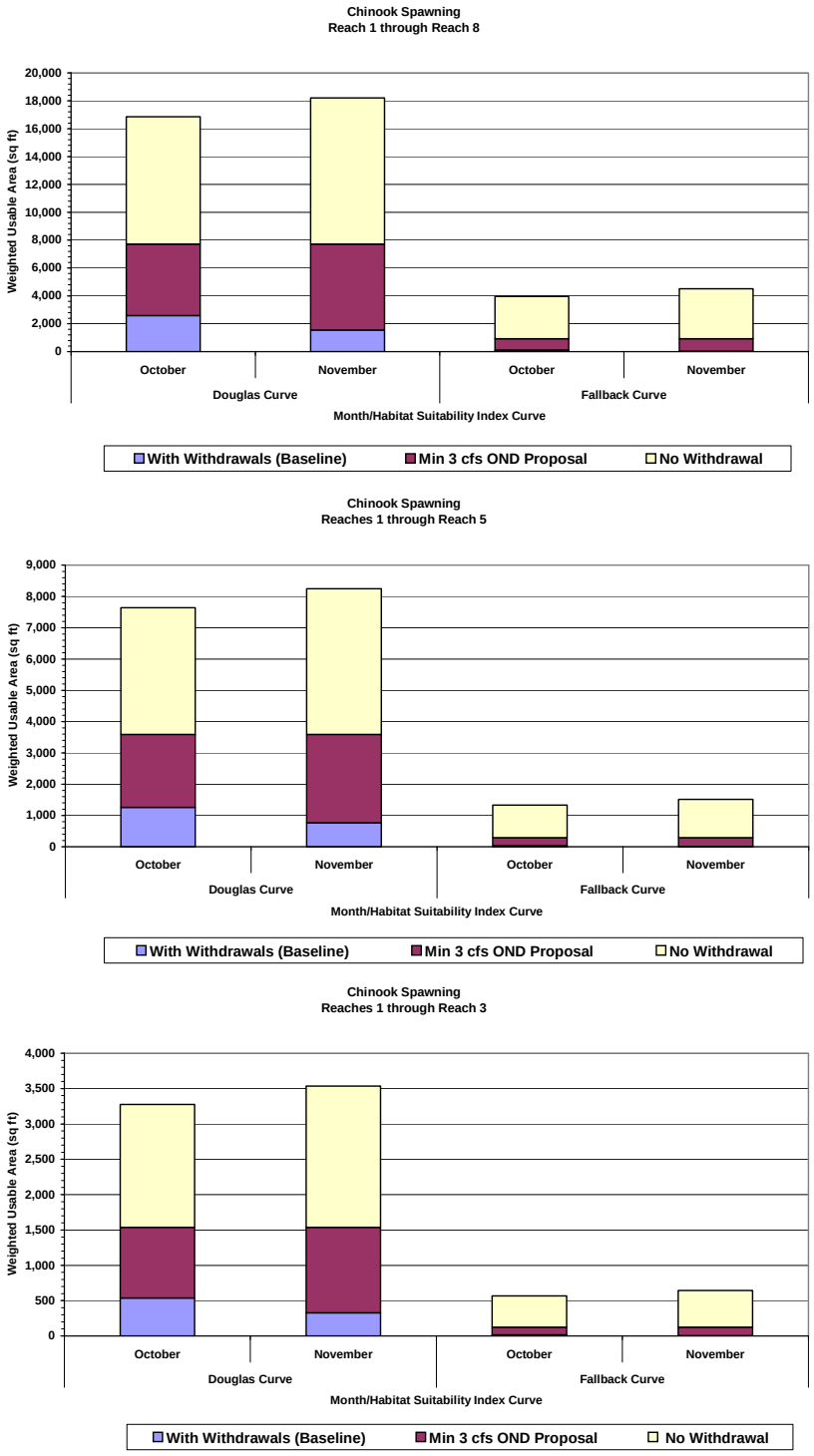
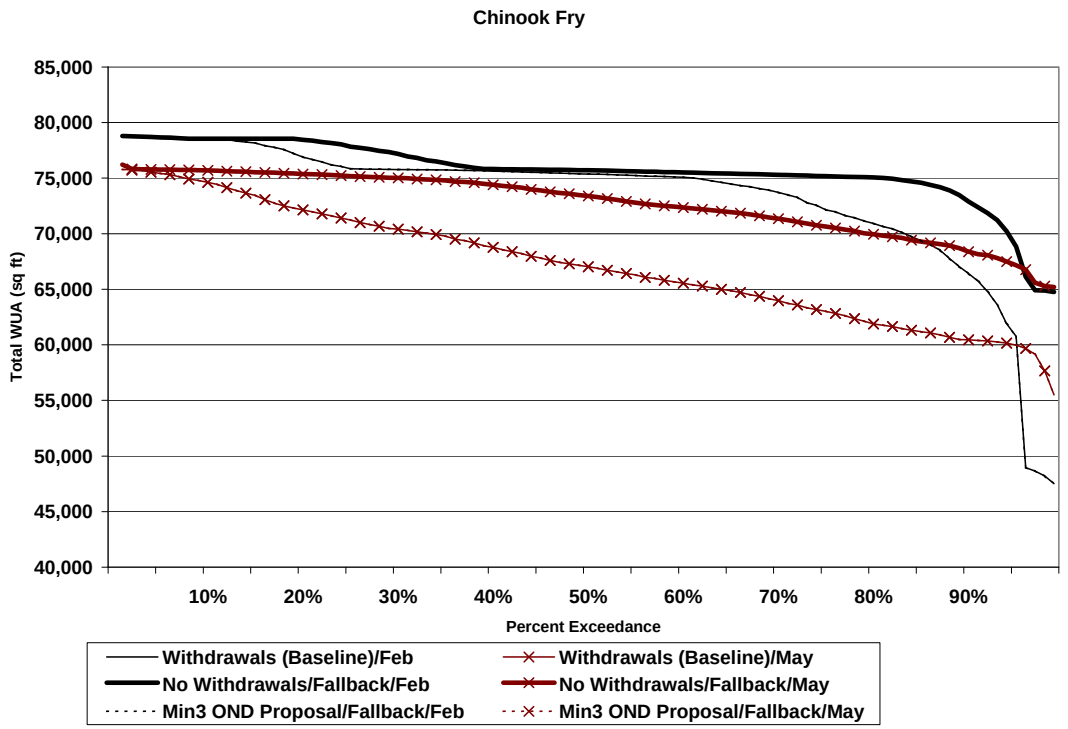



Figure 9. Chinook salmon median spawning WUA under three alternative distributions.



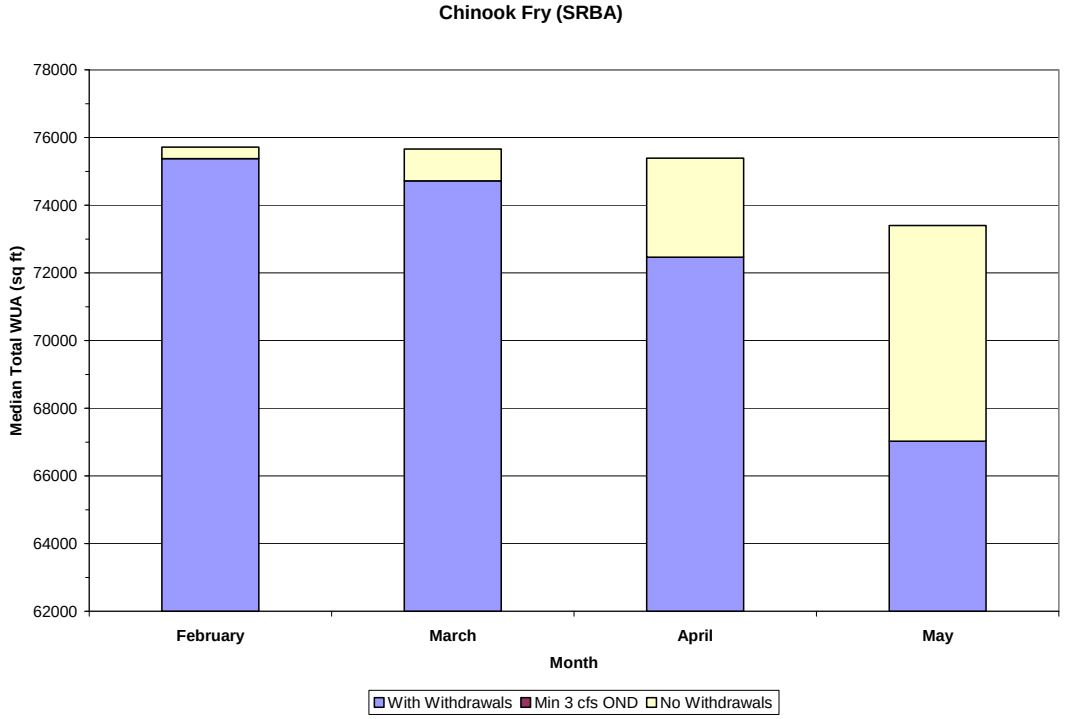




Figure 10. Total weighted usable area for Chinook fry from Reach 1 to Reach 9b downstream of the Parshall Flume. Exceedance values (top); median values (bottom).

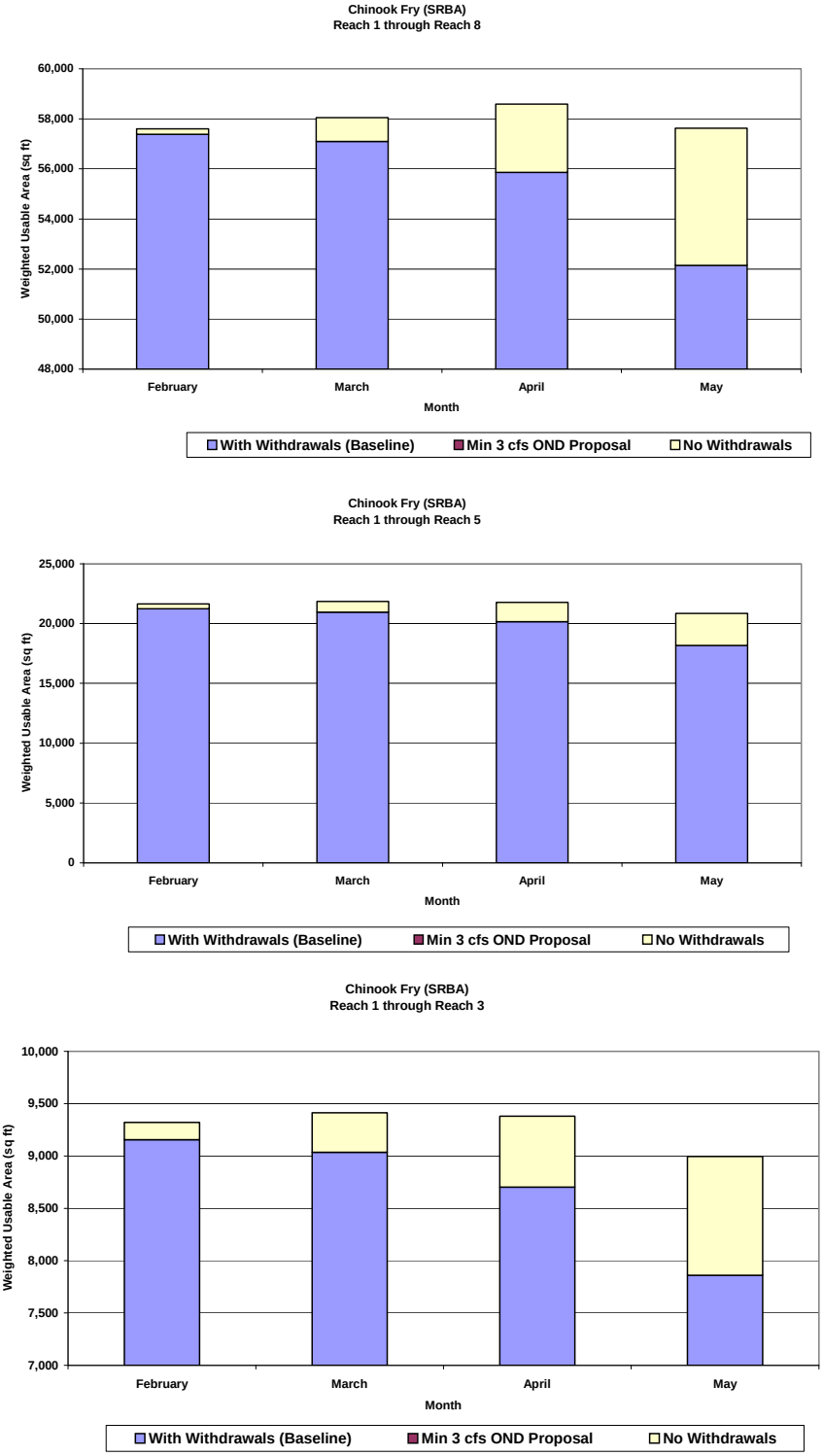
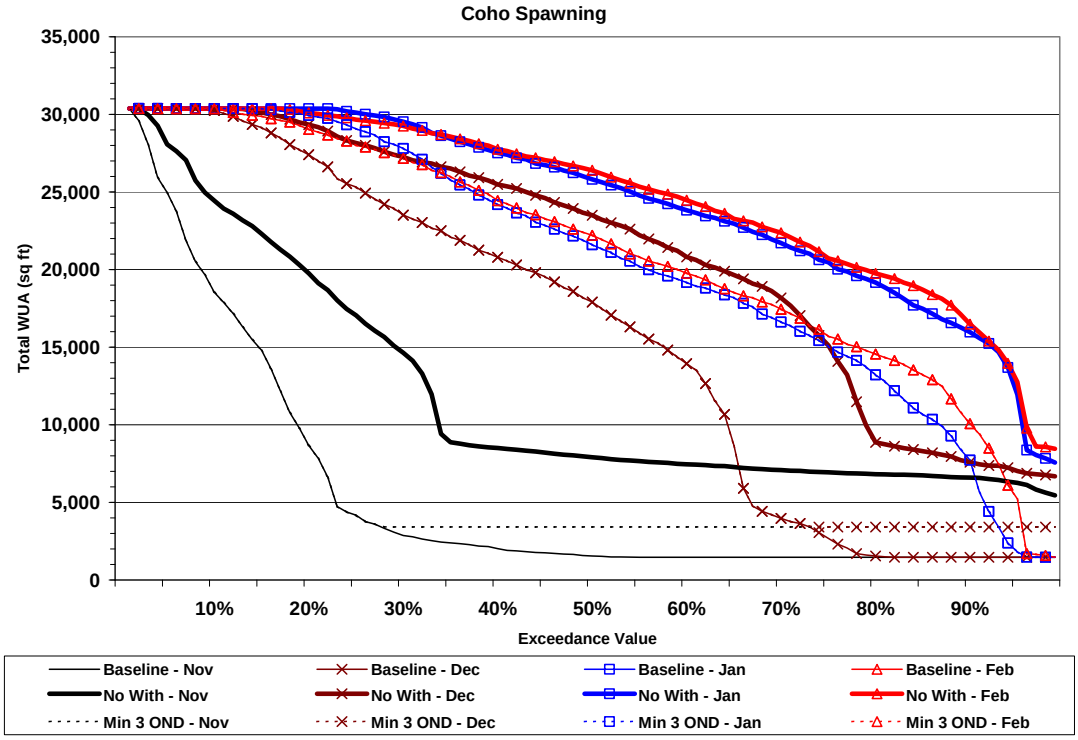



Figure 11. Chinook salmon median fry WUA under three alternative distributions.



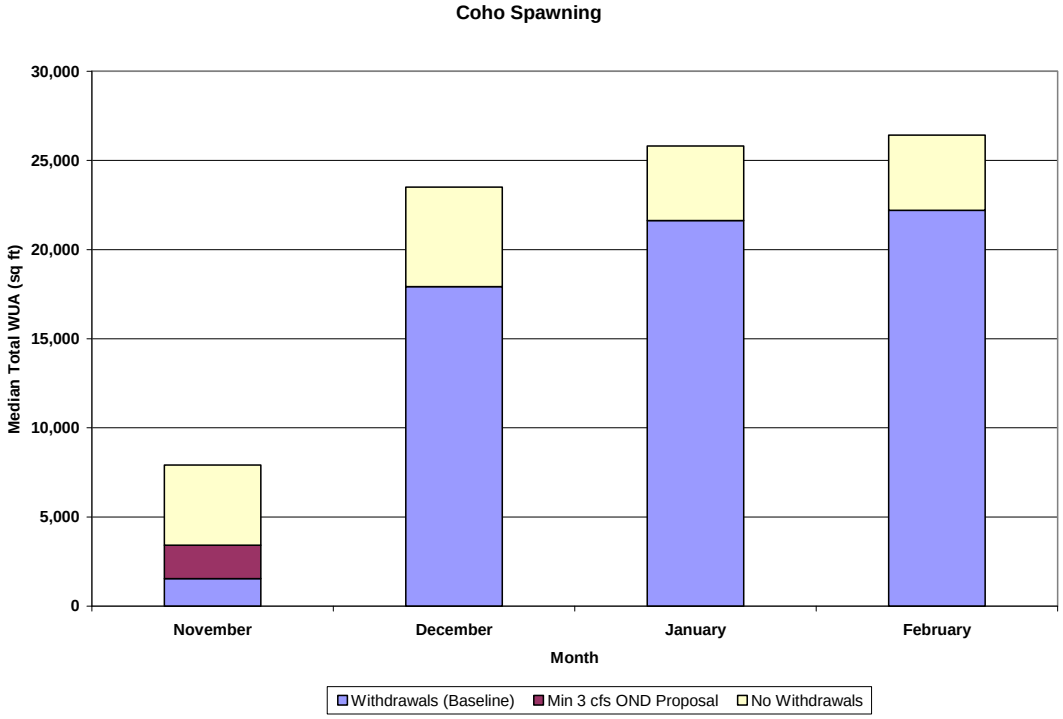
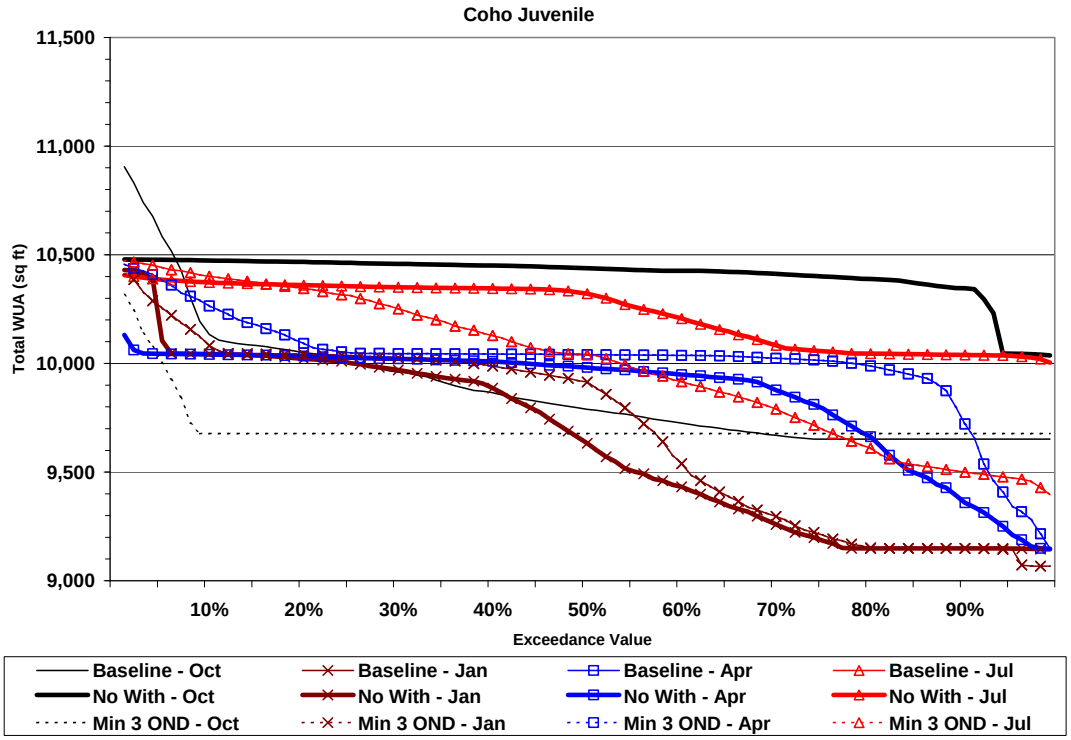




Figure 12. Total weighted usable area for coho spawning from Reach 1 to Reach 9b downstream of the Parshall Flume. Exceedance values (top); median values (bottom).



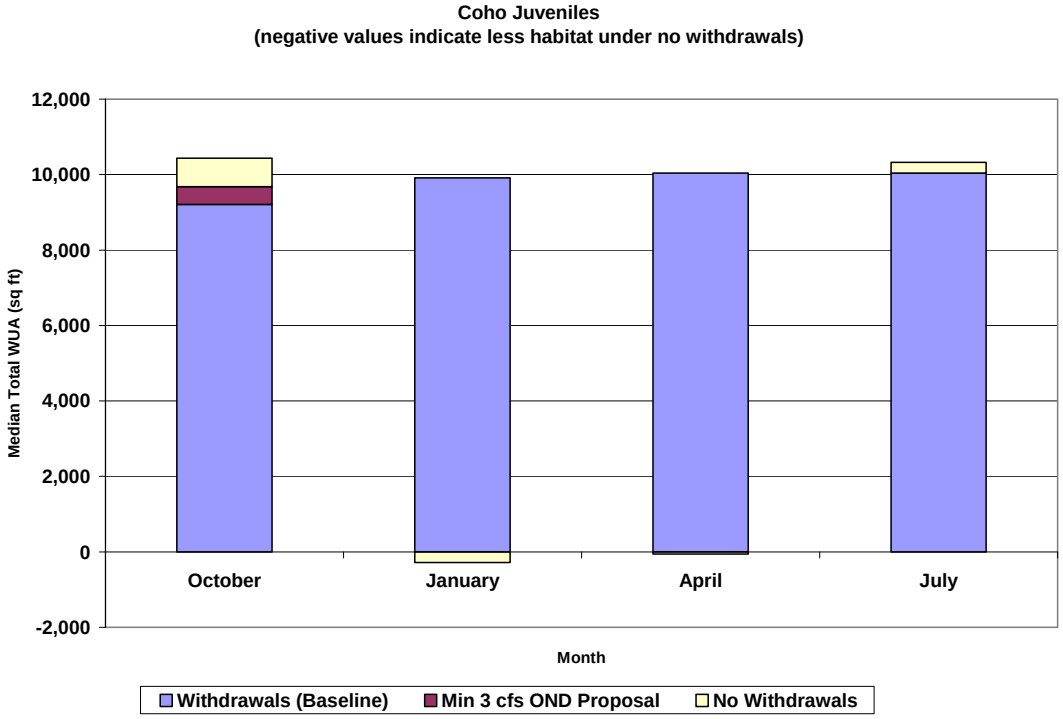
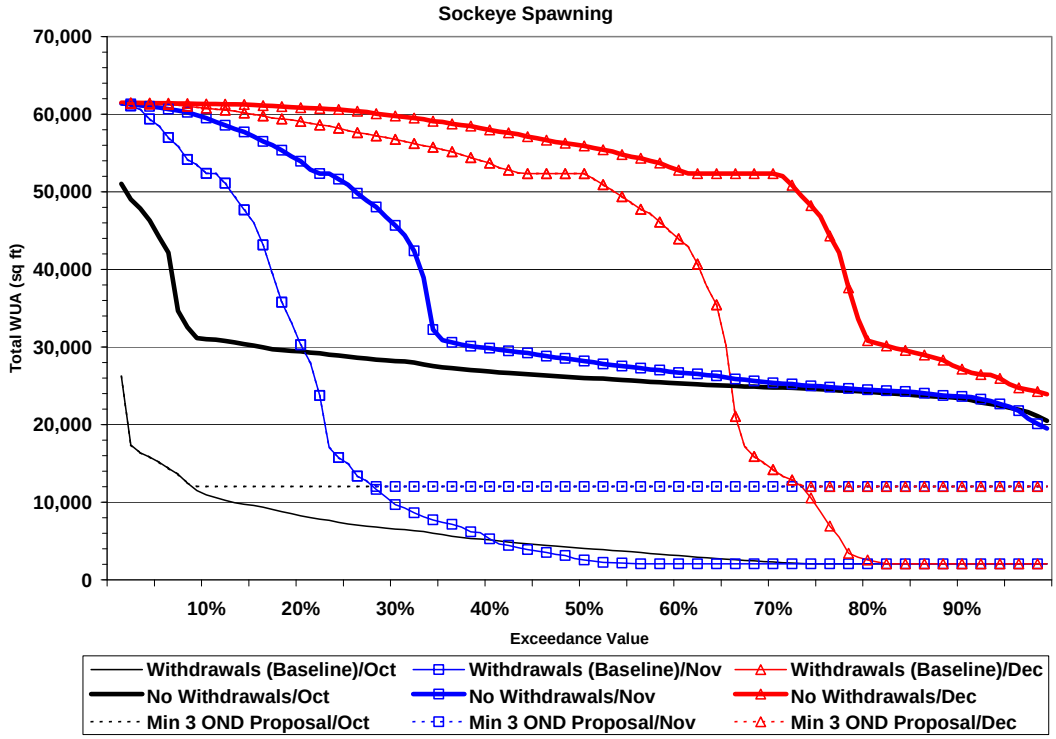




Figure 13 Total weighted usable area for coho juveniles from Reach 1 to Reach 9b downstream of the Parshall Flume. Exceedance values (top); median values (bottom).



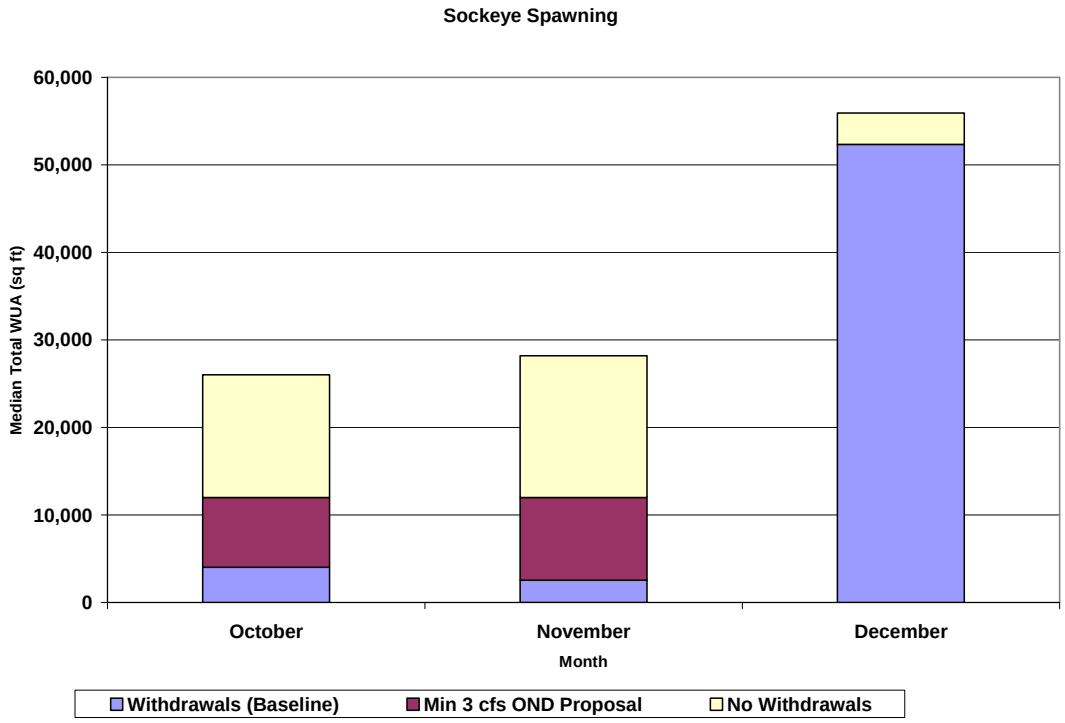
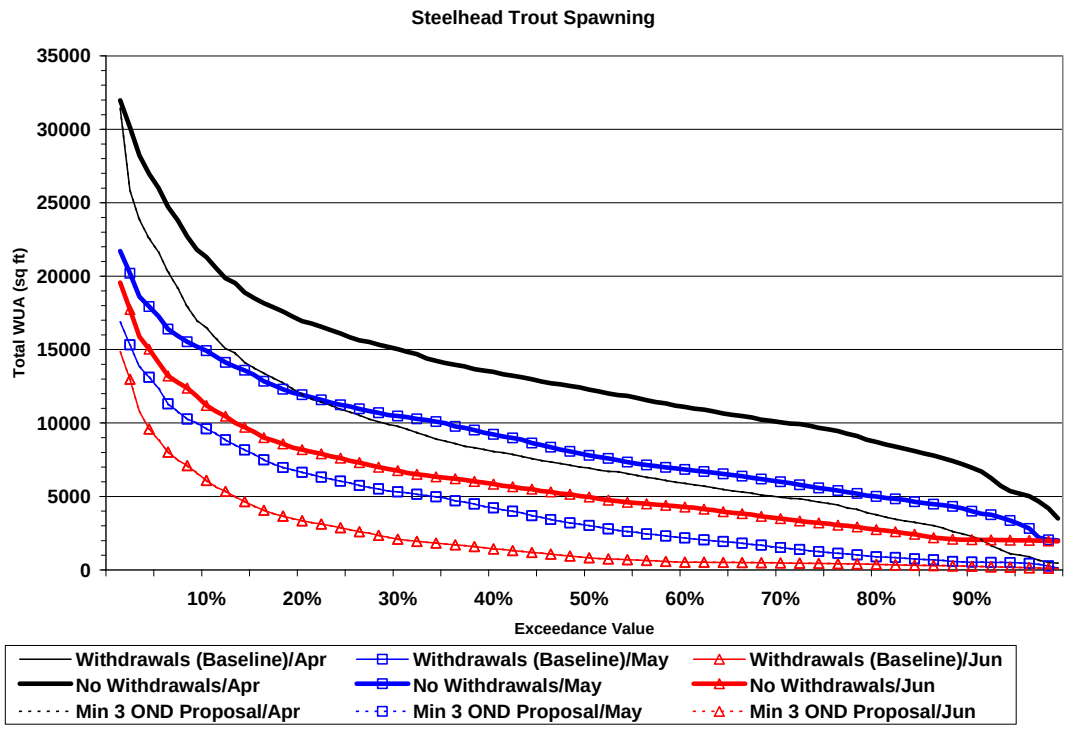




Figure 14. Total weighted usable area for sockeye spawning from Reach 1 to Reach 9b downstream of the Parshall Flume. Exceedance values (top); median values (bottom).



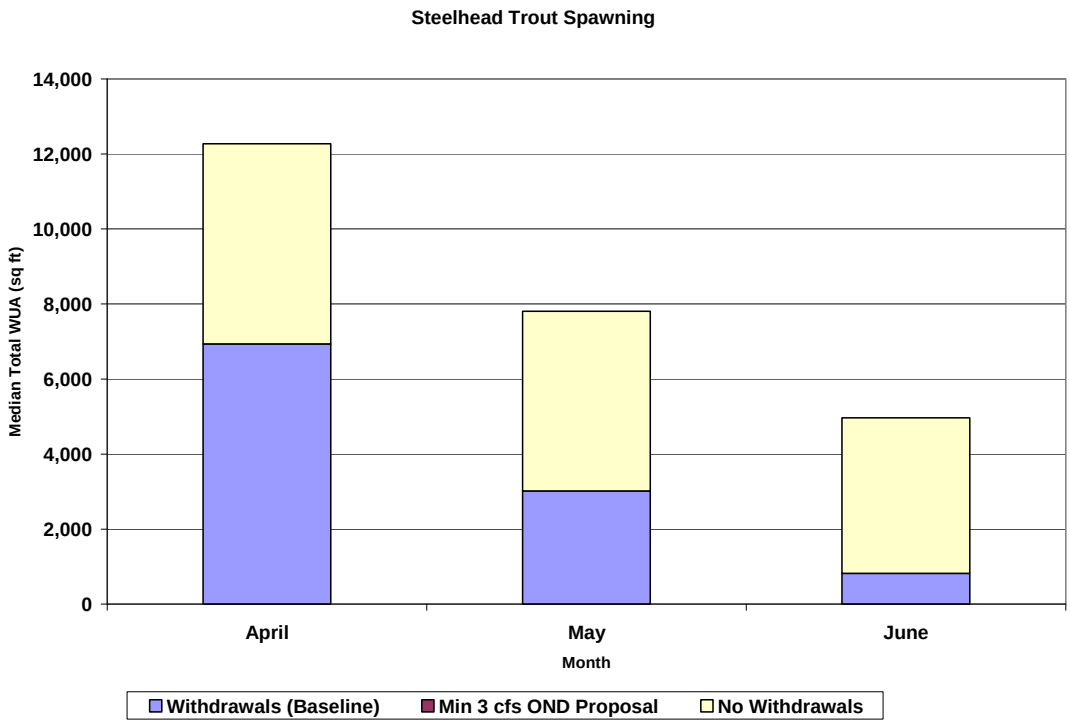
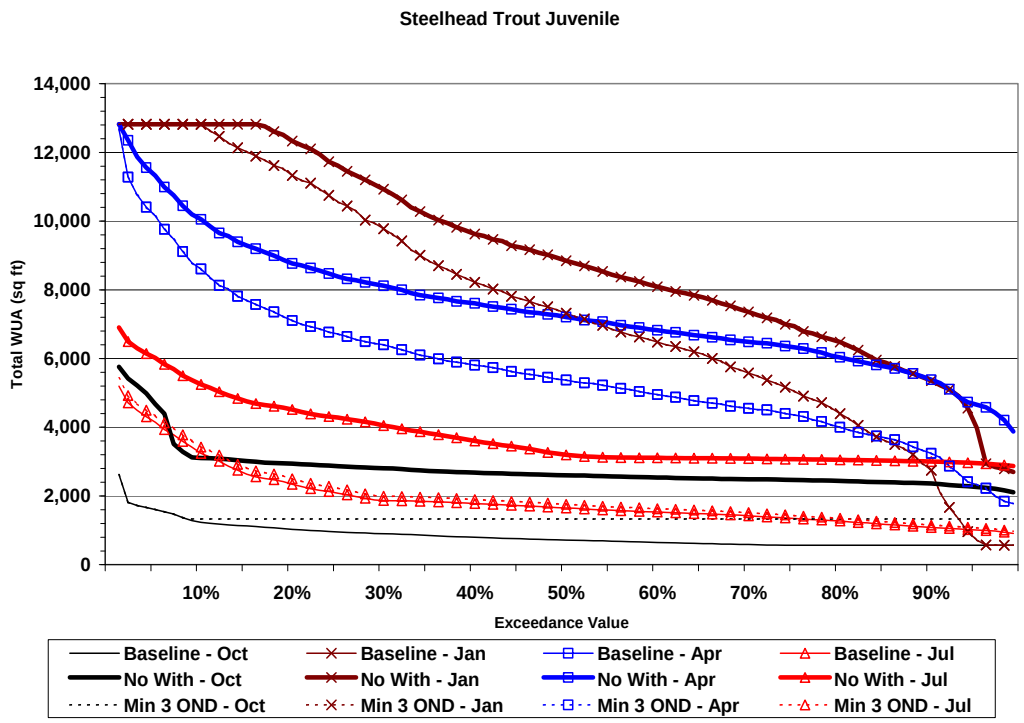




Figure 15. Total weighted usable area for steelhead trout spawning from Reach 1 to Reach 9b downstream of the Parshall Flume. Exceedance values (top); median values (bottom).



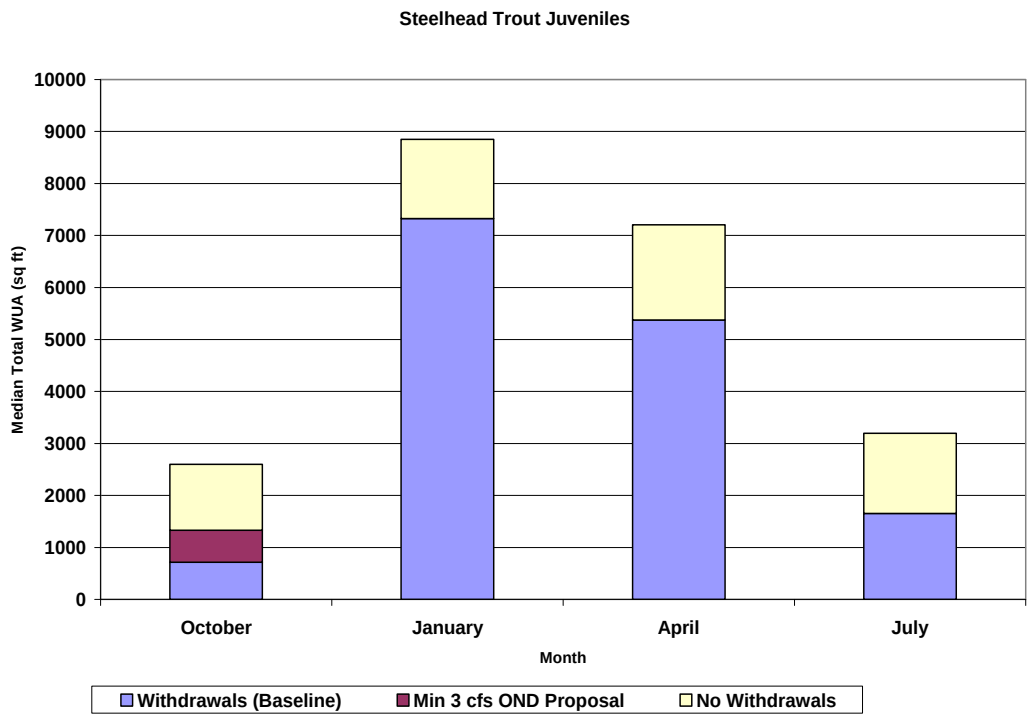
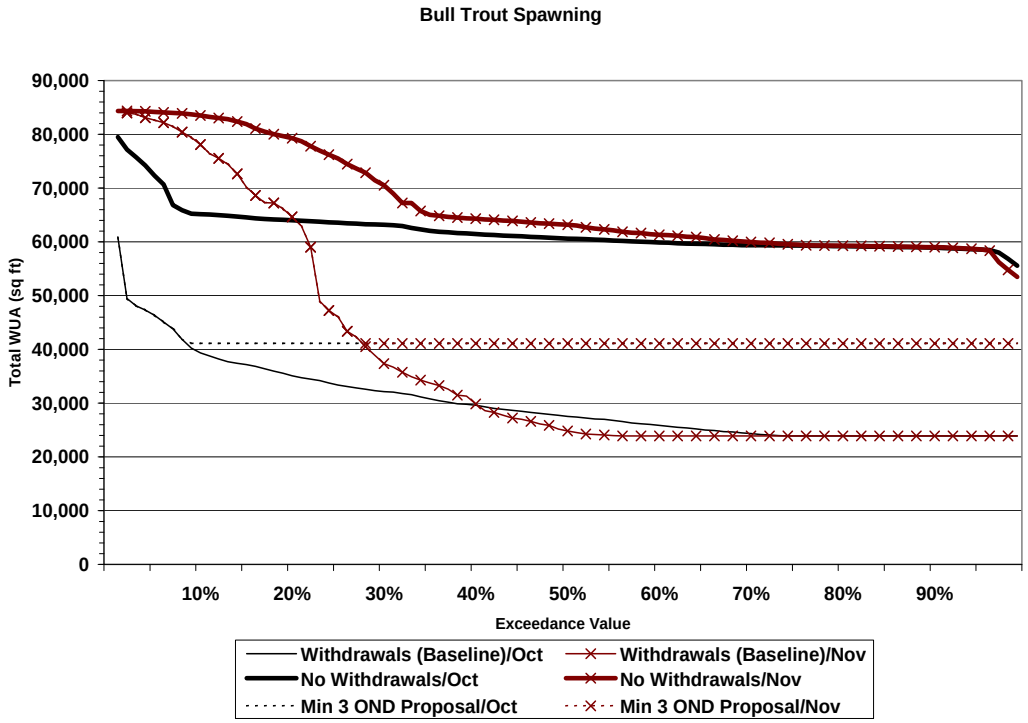




Figure 16. Total weighted usable area for steelhead trout juveniles from Reach 1 to Reach 9b downstream of the Parshall Flume. Exceedance values (top); median values (bottom).



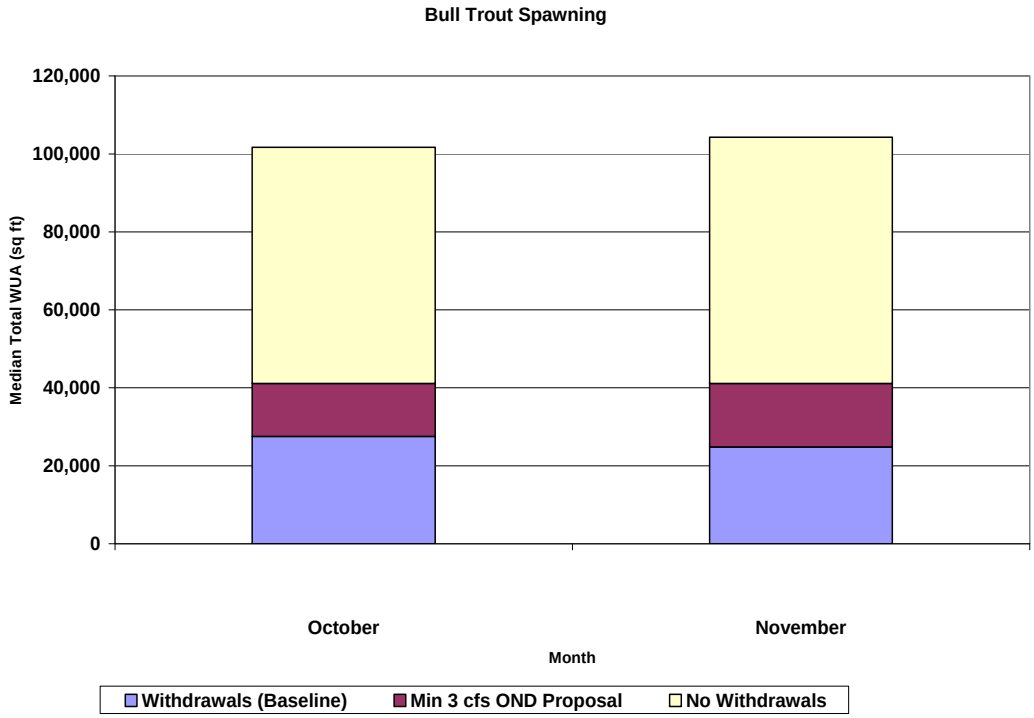
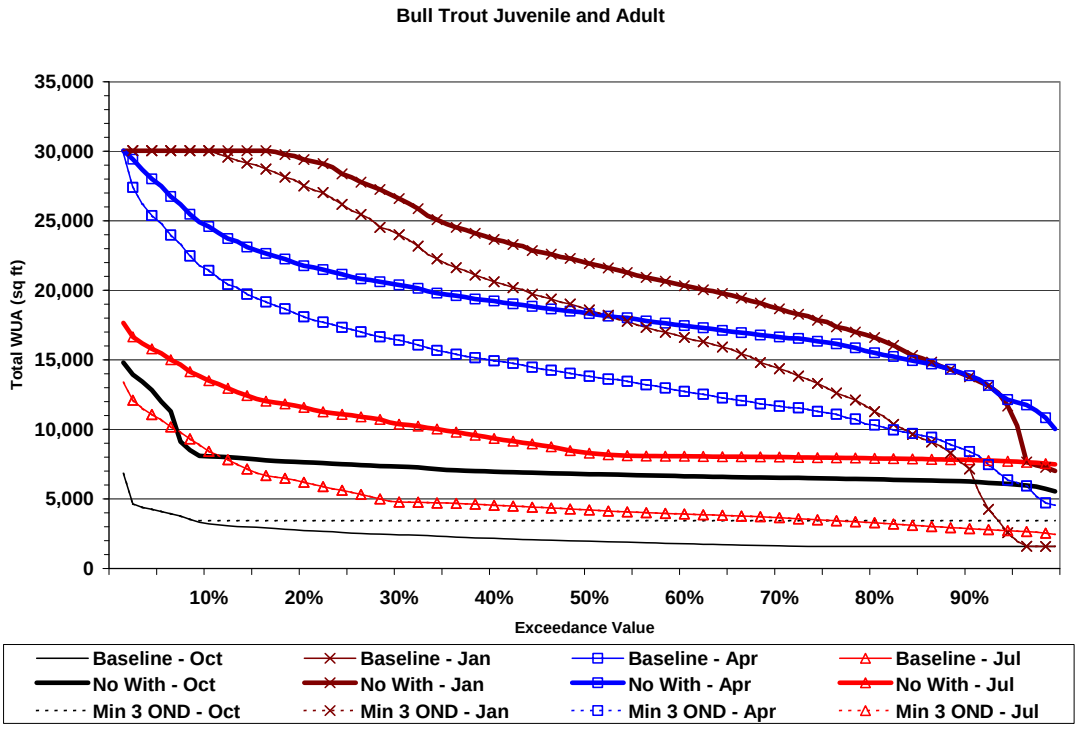




Figure 17 Total weighted usable area for bull trout spawning from Reach 1 to Reach 9b downstream of the Parshall Flume. Exceedance values (top); median values (bottom).



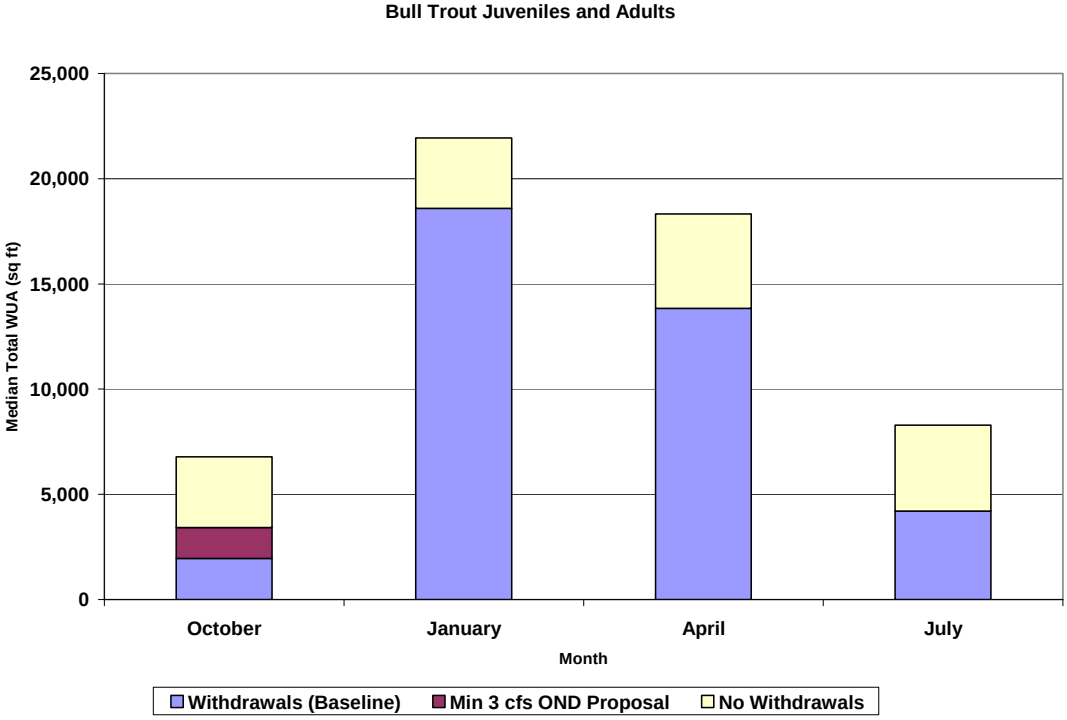
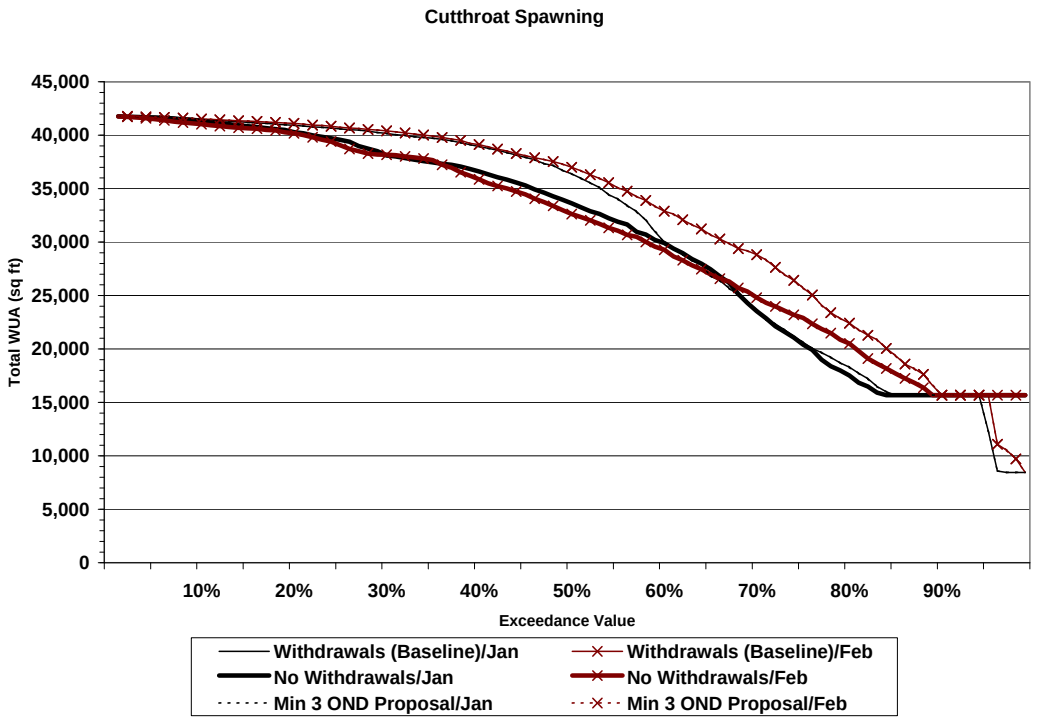




Figure 18. Total weighted usable area for bull trout juveniles from Reach 1 to Reach 9b downstream of the Parshall Flume. Exceedance values (top); median values (bottom).



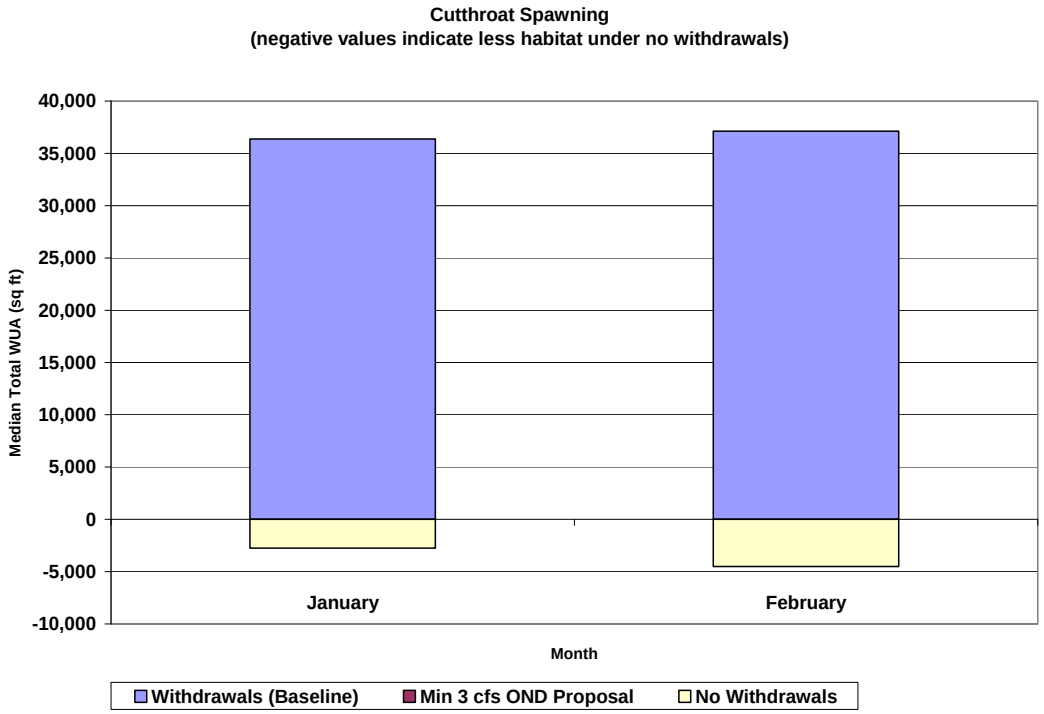
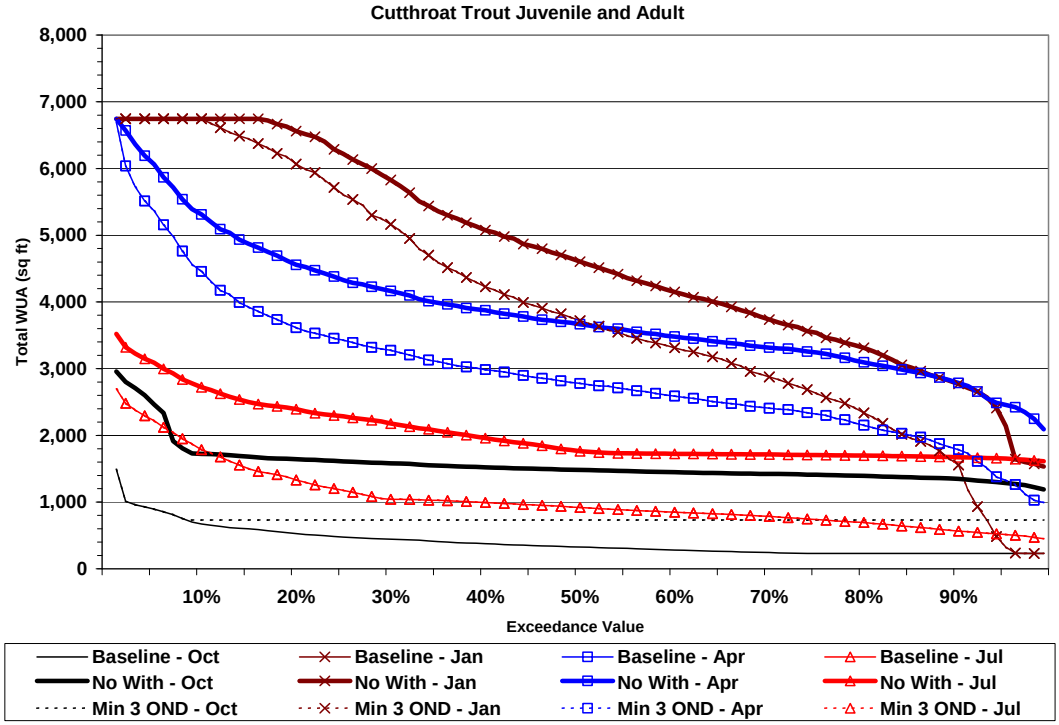




Figure 19. Total weighted usable area for cutthroat trout spawning from Reach 1 to Reach 9b downstream of the Parshall Flume. Exceedance values (top); median values (bottom).



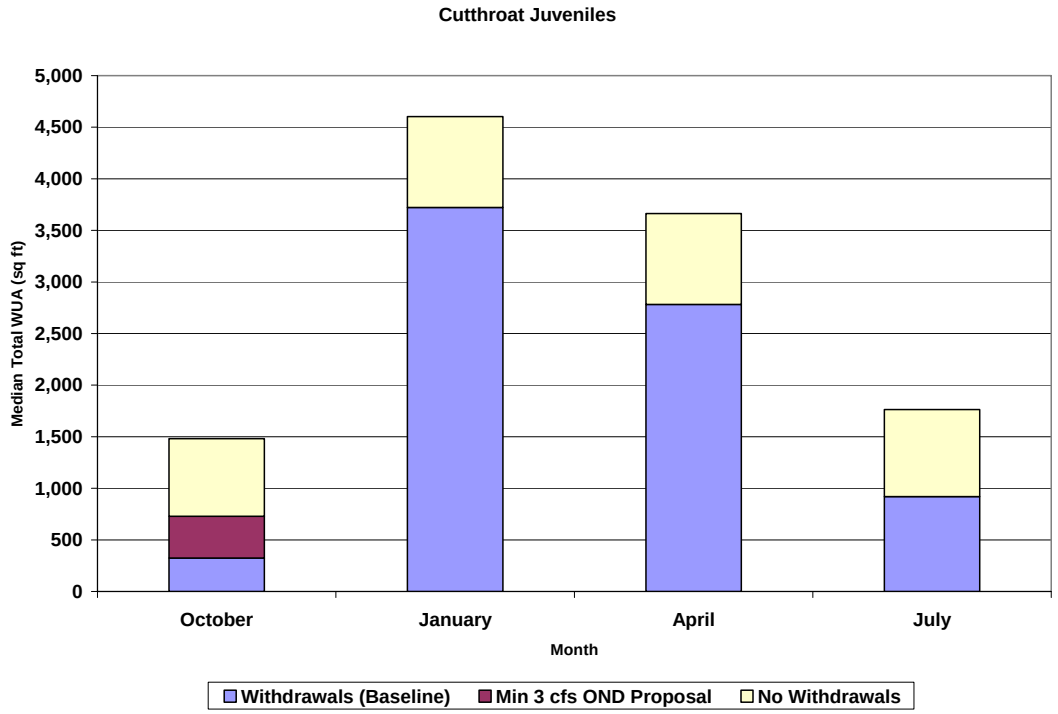
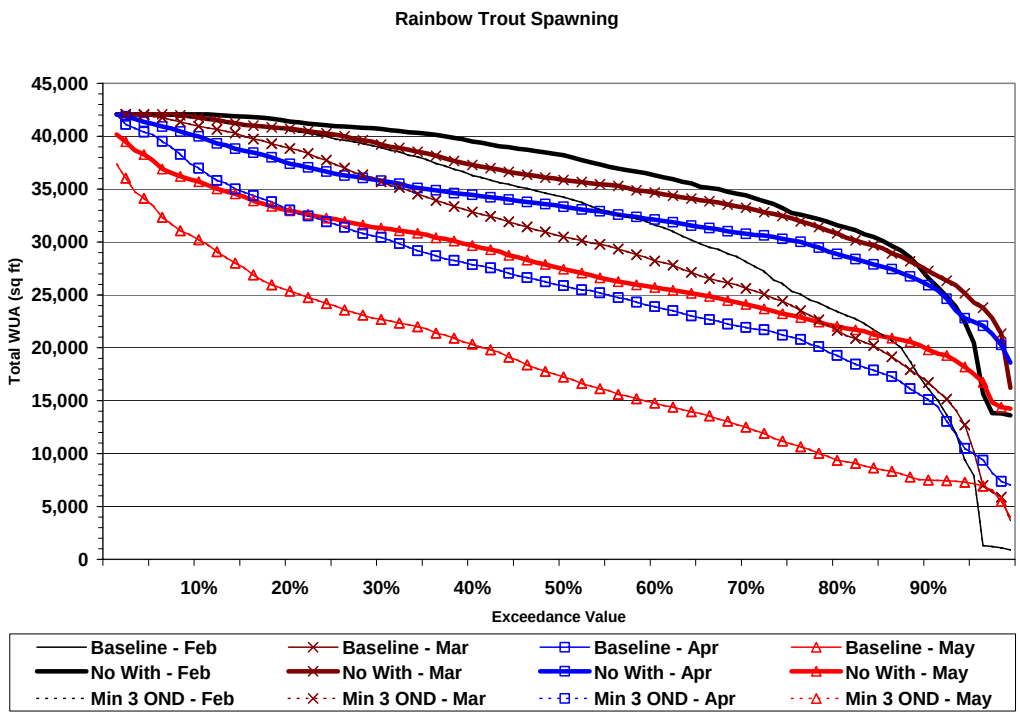




Figure 20. Total weighted usable area for cutthroat trout juveniles and adults from Reach 1 to Reach 9b downstream of the Parshall Flume. Exceedance values (top); median values (bottom).



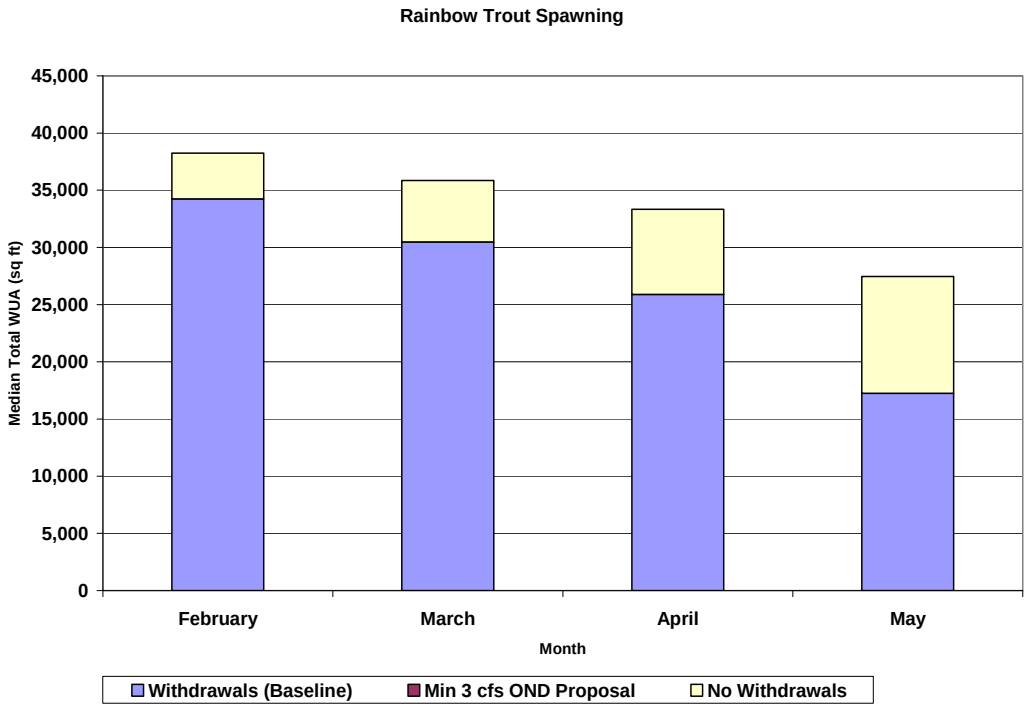
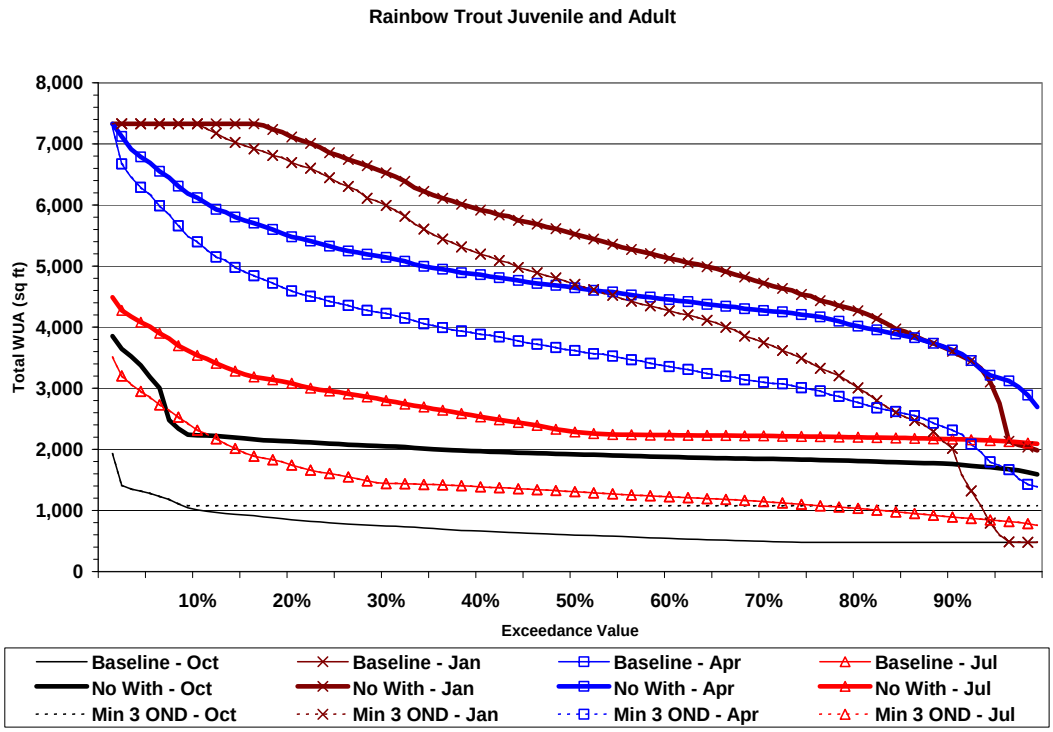




Figure 21. Total weighted usable area for rainbow trout spawning from Reach 1 to Reach 9b downstream of the Parshall Flume. Exceedance values (top); median values (bottom).



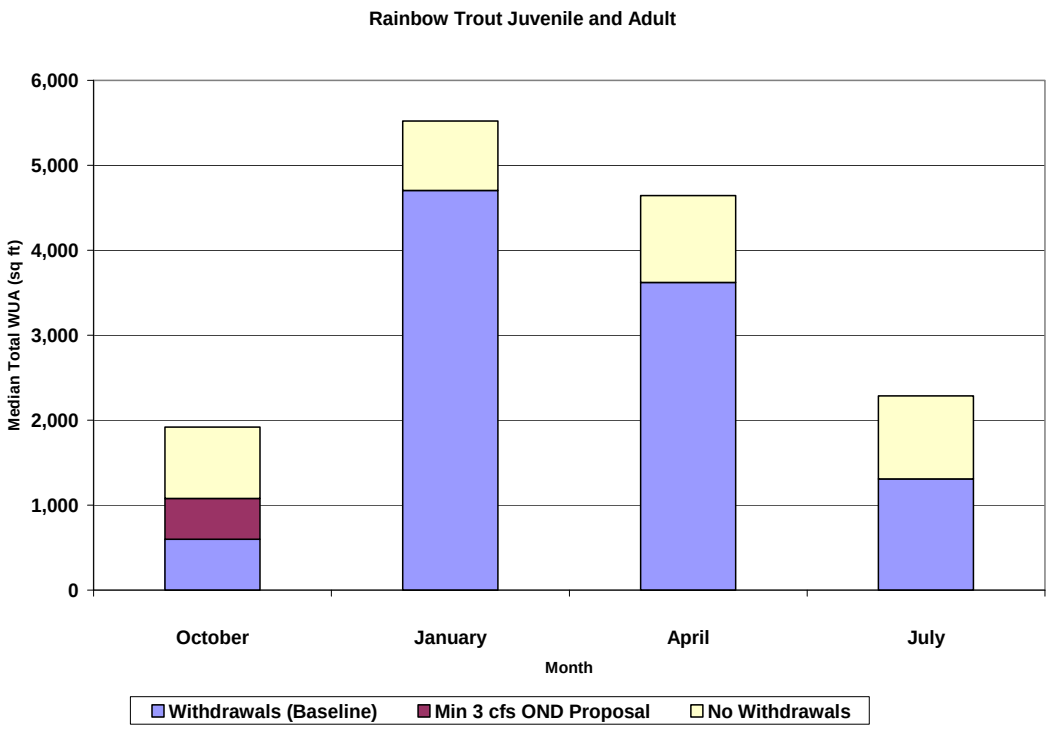
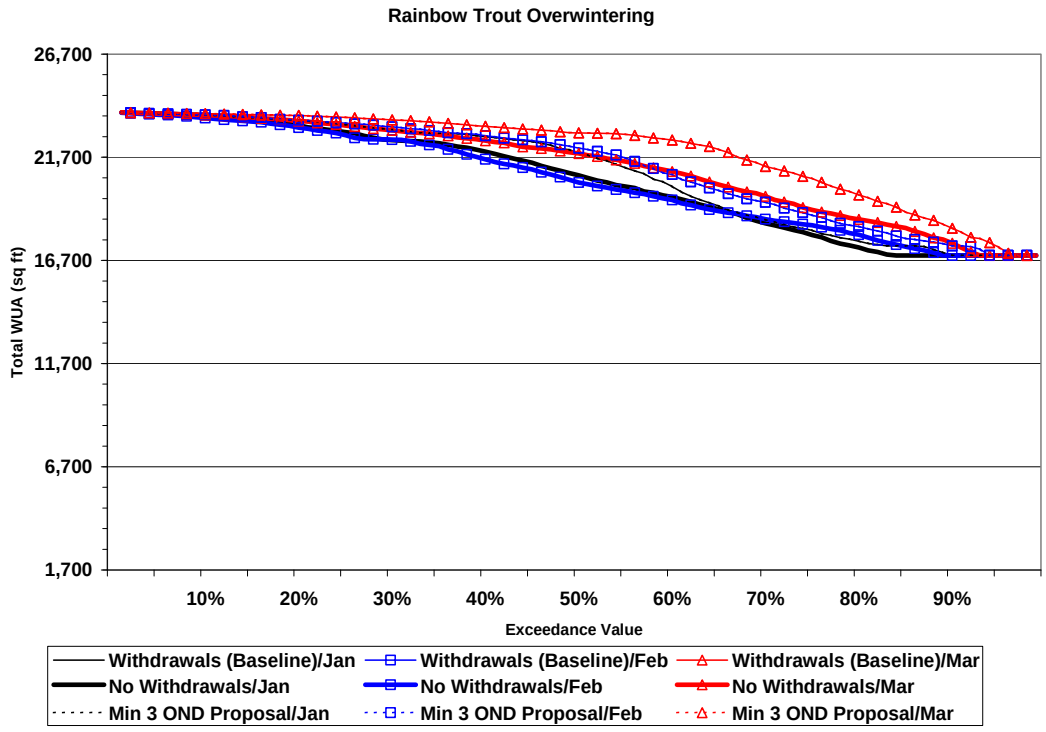




Figure 22. Total weighted usable area for rainbow trout juveniles and adults from Reach 1 to Reach 9b downstream of the Parshall Flume. Exceedance values (top); median values (bottom).



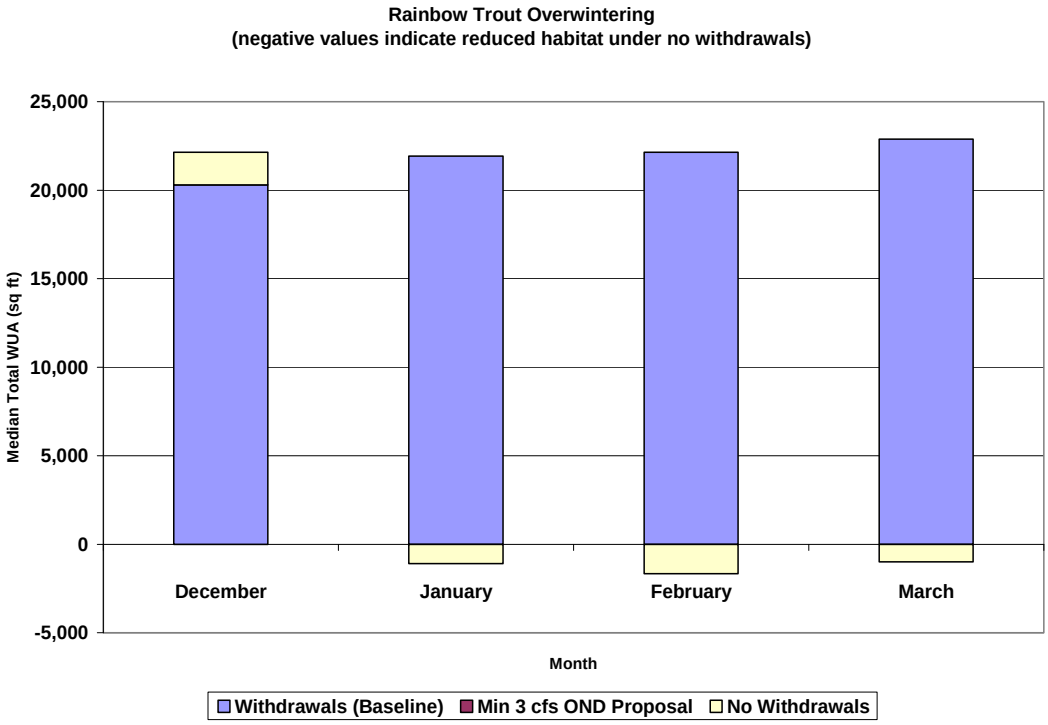




Figure 23. Total weighted usable area for rainbow trout overwintering from Reach 1 to Reach 9b downstream of the Parshall Flume. Exceedance values (top); median values (bottom).

Table 1. PHABSIM Site Information.

| Site | Approximate Site Location (RM) | Number of Transects | Field Collection Dates | | | Mean Measured Flow (cfs) | | |
|---|---|---|---|---|---|---|---|---|
| | | | Low | Medium | High | Low | Medium | High |
| 1 | 0.4 | 10 | 10/30/01 | 11/16/01 | 1/24/02 | 3.8 | 10.8 | 29.1 |
| 2 | 1.6 | 9 | | 11/16/01 | 1/30/02 | 4.5 | 6.9 | 34.0 |
| 3 | 2.0 | 9 | | 11/19/01 | 1/28/02 | 2.1 | 7.1 | 29.4 |
| A | 0.2 | 3 | 8/11/2004 | 5/5/2004 | 6/3/2004 | 2.7 | 5.6 | 10.7 |
| B | 0.6 | 3 | 8/11/2004 | 5/5/2004 | 6/3/2004 | 2.6 | 6.3 | 10.6 |
| C | 0.7 | 3 | 8/11/2004 | 5/5/2004 | 6/3/2004 | 2.8 | 6.3 | 10.9 |

Table 2. Transect Habitat Type.

| Site | Transect(s) | Habitat Type | Stream Length Represented (ft) |
|---|---|---|---|
| 1 | 1 | Riffle | 3.4 |
| 1 | 2 | Riffle | 8.2 |
| 1 | 3 | Riffle | 7.4 |
| 1 | 4 | Riffle | 7.5 |
| 1 | 5 | Riffle | 10.0 |
| 1 | 6 | Riffle | 7.9 |
| 1 | 7 | Riffle | 5.8 |
| 1 | 8 | Riffle | 6.7 |
| 1 | 9 | Riffle | 5.9 |
| 1 | 10 | Riffle | 2.1 |
| 2 | 1 | Run | 7.4 |
| 2 | 2 | Run | 12.0 |
| 2 | 3 | Riffle | 9.5 |
| 2 | 4 | Riffle | 9.3 |
| 2 | 5 | Run | 13.8 |
| 2 | 6 | Riffle | 16.4 |
| 2 | 7 | Riffle | 10.4 |
| 2 | 8 | Riffle | 7.7 |
| 2 | 9 | Riffle | 4.3 |
| 3 | 1 | Run | 7.2 |
| 3 | 2 | Run | 12.1 |
| 3 | 3 | Run | 12.3 |
| 3 | 4 | Run | 13.4 |
| 3 | 5 | Run | 12.9 |
| 3 | 6 | Run | 13.4 |
| 3 | 7 | Run | 18.1 |
| 3 | 8 | Run | 18.9 |
| 3 | 9 | Run | 7.4 |
| A | 1 | Pool | 13.5 |
| A | 2 | Pool | 40.5 |
| A | 3 | Riffle | 108.0 |
| B | 1 | Riffle | 11.5 |
| B | 2 | Riffle | 19.9 |
| B | 3 | Pool | 20.0 |
| C | 1 | Pool | 10.0 |
| C | 2 | Pool | 27.9 |
| C | 3 | Riffle | 17.9 |

Table 3. Habitat Suitability curves Used in the PHABSIM Analysis.

| Species | Life-History Stage | Depth | Velocity | Substrate |
|---|---|---|---|---|
| Chinook | Spawning | Douglas County, WDFW Fallback Figure 1a | Douglas County, WDFW Fallback Figure 1b | WDFW Fallback Generic Salmon Table 2 |
| | Fry | Snake River Basin Adjudication | Snake River Basin Adjudication | Snake River Basin Adjudication |
| | Juvenile | WDFW Fallback Figure 2a | WDFW Fallback Figure 2b | WDFW Fallback Generic Salmon and Trout Table 3 |
| Sockeye | Spawning | WDFW Fallback Figure 9a | WDFW Fallback Figure 9b | WDFW Fallback Generic Salmon Table 2 |
| Bull Trout | Spawning | WDFW Fallback Figure 17a | WDFW Fallback Figure 17b | WDFW Fallback Generic Native Char Table 8 |
| | Juvenile/Adult | WDFW Fallback Figure 18a | WDFW Fallback Figure 18b | WDFW Fallback Generic Trout Table 7 |
| Coho | Spawning | WDFW Fallback Figure 4a | WDFW Fallback Figure 4b | WDFW Fallback Generic Salmon Table 2 |
| | Juvenile | WDFW Fallback Figure 5a | WDFW Fallback Figure 5b | WDFW Fallback Generic Salmon and Trout Table 3 |
| Steelhead | Spawning | WDFW Fallback Figure 10a | WDFW Fallback Figure 10b | WDFW Fallback Table 5 |
| | Juvenile | WDFW Fallback Figure 11a | WDFW Fallback Figure 11b | WDFW Fallback Generic Trout Table 7 |
| Cutthroat Trout | Spawning | WDFW Fallback Figure 15a | WDFW Fallback Figure 15b | WDFW Fallback Generic Trout Table 6 |
| | Juvenile/Adult | WDFW Fallback Figure 16a | WDFW Fallback Figure 16b | WDFW Fallback Generic Trout Table 7 |
| Rainbow Trout | Spawning | WDFW Fallback Figure 12a | WDFW Fallback Figure 12b | WDFW Fallback Generic Trout Table 6 |
| | Juvenile/Adult | WDFW Fallback Figure 13a | WDFW Fallback Figure 13b | WDFW Fallback Generic Trout Table 7 |
| | Overwintering | WDFW Fallback Figure 14a | WDFW Fallback Figure 14b | WDFW Fallback Generic Trout Table 7 |

Table 4. Length (ft) of Rock Creek in each of five habitat types.

| | HabitatType | | | | | |
|---|---|---|---|---|---|---|
| **Reach** | **Braided Channel** | **Cascade** | **Pool** | **Riffle** | **Run/Glide** | **Grand Total** |
| Reach 1 | | 17 | | 342 | | 359 |
| Reach 2 | | | 78 | 390 | 31 | 495 |
| Reach 3 | | 106 | 54 | 435 | 47 | 642 |
| Reach 4a | | | 63 | 196 | 30 | 289 |
| Reach 4b | | | 60 | 600 | 39 | 699 |
| Reach 5 | | | 32 | 904 | 58 | 994 |
| Reach 6 | | 101 | 18 | 570 | 32 | 721 |
| Reach 7 | | | | 560 | | 560 |
| Reach 8 | 1,131 | | 535 | 950 | 682 | 3,298 |
| Reach 9 | | | | | 158 | 158 |
| Reach 9b[1] | 979 | | 66 | | 932 | 1,977 |
| Reach 10 | | | | 216 | 503 | 719 |
| Reach 11 | | | 195 | 34 | 235 | 464 |
| Reach 12 | 241 | | 258 | 42 | 781 | 1,322 |
| Reach 13 | 254 | | 152 | 55 | 1,338 | 1,799 |
| **Grand Total** | 2,689 | 224 | 1,511 | 5,206 | 4,866 | 14,496 |

[1] Upstream of the Parshall Flume, Reach 9b included 289 feet of Run/Glide and 206 feet of Braided Channel.

Table 5. Species and life stage periodicity information used in the PHABSIM/HSPF Linked Operations Analysis Tool.

| Species | Lifestage | Months of Interest | | | |
|---|---|---|---|---|---|
| Chinook | Spawning | October | November | | |
| Chinook | Fry | February | March | April | May |
| Coho | Spawning | November | December | January | February |
| Coho | Juvenile | September | November | February | May |
| Bull Trout | Spawning | October | November | | |
| Bull Trout | Juvenile | September | November | February | May |
| Bull Trout | Adult | September | November | February | May |
| Sockeye | Spawning | October | November | December | |
| Cutthroat | Spawning | January | February | | |
| Cutthroat | Juvenile | September | November | February | May |
| Cutthroat | Adult | September | November | February | May |
| Steelhead | Spawning | March | April | May | |
| Steelhead | Juvenile | September | November | February | May |
| Rainbow Trout | Spawning | February | March | April | May |
| Rainbow Trout | Juvenile | September | November | February | May |
| Rainbow Trout | Adult | September | November | February | May |
| Rainbow Trout | Winter | December | January | February | March |

*This page intentionally left blank.*

# APPENDIX G

## Clark Springs Water Supply System HCP
## Operational Constraints White Paper

*This page intentionally left blank.*

*Appendix G*

# Clark Springs Water Supply System
# Habitat Conservation Plan
# Operational Constraints White Paper

***Completed by the City of Kent***
***Public Works Department***

***October 2007***
***updated February 2009***

**Rock Creek HCP**
**Operational Constraints White Paper**

## I. Introduction

In January 2001, as a measure to solidify certainty and reliability of its Clark Springs water supply system, the City Council directed staff to prepare a Habitat Conservation plan (HCP) with the intention of acquiring an Incidental Take Permit (ITP). To date, the City, with the assistance of its consultant teams, has performed and completed an abundant amount of technical studies and analysis surrounding the Rock Creek Watershed and operations of the City's Clark Springs water supply facility.

Negotiations surrounding the HCP and ITP are currently underway with the NOAA Fisheries and US Fish and Wildlife (herein after Services). At the January 6, 2005 negotiation meeting, a number of questions were raised by the Services which pertained to the constraints of the City's Clark Springs water supply system, and the Kent water system as a whole.

Although operational constraints are present within the City's water supply system, as detailed within this paper, the City has been proactive in utilizing its current water supply system, to the most efficient extent practicable, to meet its primary obligation of ensuring and providing a sufficient supply of water to meet its health and life safety demands while also being stewards of the environment. Stewardship efforts have included, but have not been limited to, conservation, education, wellhead protection, re-drilling wells to reclaim lost productivity, reducing unaccounted for water, voluntary flow augmentation, and participating in regional water supply efforts such as the Tacoma Second Supply water project. In addition, the City has been stewards of the Clark Springs property to help maintain the habitat for aquatic and terrestrial species within the watershed.

## II. Description of the Watershed

### A. Location

The Rock Creek Watershed is located southeast of Maple Valley on the eastern portion of the Covington Uplands within the southeastern portion of the Puget Sound lowland where it merges into the glaciated foothills of the Cascade range. The watershed lies between the Cedar River to the north, and the Green River to the south. The mouth of Rock Creek enters the Cedar River on the left bank of River Mile (RM) 18.15. The watershed is approximately 15.68 square miles based on maps created at 5-foot contour intervals commissioned by the City of Kent.

### B. Shallow unconfined aquifer

The unique geologic history of the Rock Creek watershed has played a significant role in shaping the watershed and creating complex conditions. To understand the aquifer, one must also understand the geology. This is an extremely brief overview of the geology.

For a more detailed description, please refer to the Hydrology of Rock Creek Report, dated May 1, 2003, completed by Hart Crowser.

The geology of the watershed consists of consolidated Tertiary bedrock overlain by unconsolidated sediments deposited during the Quaternary period (the last 750,000 years). The small hills that surround the watershed are made up of the Tertiary (approx. 1.6 to 65 million years before present) bedrock. Approximately 15,000 years ago, the Vashon glacial advance deposited sediments within the watershed (Hart Crowser, 2003). These deposits generally included till on the bedrock hills surrounding the watershed and recessional outwash deposits in the valley. These recessional outwash deposits in the valley comprise the aquifer in which Clark Springs is located. Generally the aquifer is highly transmissive, shallow, and unconfined.

## C. Precipitation driven system – variability

1. Clark Springs System

The temperate climate of the Puget Sound Lowland, exemplified by generally mild temperatures with wet winters and dry summers are typical of the watershed area. Recently there have been some notably dry years (e.g., 2001 and 2002), with rainfall substantially below normal.

While other water purveyors in the region who have secured HCP's have water sources that are dependent on snow pack, Kent's aquifers are dependent on winter precipitation in the form of rain. The typical wet season in the Puget Sound region lasts from approximately October to March. The foothills surrounding the Rock Creek watershed are not high enough in elevation to accumulate any sustainable snowpack to recharge the aquifer later in the year. The tallest foothill in the watershed is Sugarloaf Mountain at 1483 ft, located on the eastern boundary of the watershed.

A review of precipitation data from the Landsburg Area identifies a wide range in potential precipitation. The recorded data at Landsburg (1934-2004) shows a large variation in monthly and seasonal precipitation totals. For example, the maximum amount (17.5 inches) of precipitation in the month of January has a great deal of variability from the minimum amount of precipitation (1.84 inches). December has an even greater variability with 22.63 inches (max) and 2.03 inches (min), a variability of 20.60 inches. This information was collected from the Washington Regional Climate Center.

Drastic fluctuations in seasonal and annual precipitation totals also occur in the Rock Creek Basin, which is adjacent to Landsburg. Since the Rock Creek aquifer is dependent on frequent rainfall for recharge, it is important to analyze the rainfall record for seasonal variation when analyzing the reliability of both surface water and groundwater quantities. Aquifer levels in the Rock Creek basin are difficult if not impossible to predict in any given year until aquifer levels are at a point where it is safe to assume that the aquifer is completely recharged, and then evaluate the duration and quantity of the surface and groundwater flows for the remainder of the year. Unseasonable dry periods in late

summer, fall and even winter months can easily skew the actual quantities that are available, making the actual amount or water available in the aquifer much different from the predictions year to year.

2. Other Kent Water Sources

Kent's other sources are a mixture of shallow and deeper aquifers, several of which have seasonal variability and precipitation influenced levels similar to Clark Springs. The other deeper aquifers are generally less susceptible to seasonal rainfall. However they are located in areas of significant development within the urban growth area, and appear to be influenced by these external factors such as declining recharge rates and other users withdrawing significant amounts of water from the aquifer, lessening the reliability of those groundwater sources.

## D. No reservoir

The City of Kent does not have the ability to construct a reservoir in the Clark Springs vicinity. Any water that is available for storage passes through the Clark Springs via the groundwater system. When higher flows are present in the winter, there is no possibility for storage in the Clark Springs area due to the high transmissivity of the shallow unconsolidated aquifer.

## E. Hydrogeology

1. split system (Cedar/Green) variable

Groundwater discharges from upper Rock Creek catchment via two major avenues: The Clark Springs Watershed, which flows to the Cedar River, and the Ravensdale valley, which flows to the Green River via Ravensdale and Covington Creeks. Both discharge points consist of valleys filled with recessional outwash. The high transmissivity of the sediments allow a substantial amount of groundwater flow to leave the upper catchment along these discrete aquifer channels (Hart Crowser, 2003). It is important to note this hydrologic anomaly since not all water that falls within the Rock Creek drainage actually flows to the Cedar River. It is estimated that flow through the Ravensdale channel is slightly less in quantity (by 5 to 15 percent) than groundwater flow through the Clarks Springs watershed channel (Hart Crowser, 2003). It is also useful to note that some quantity of water leaves the basin via other channels, one being the northerly outwash channel near Hidden Lake which appears to travel towards the Cedar River drainage.

The groundwater divide between the Cedar River basin and the Green River basin is located just west of 268$^{th}$ Avenue SE. The basin divide actually moves back and forth seasonally depending on the level of the water table.

### 2. High transmisivity

The outwash plain aquifer above, or east, of Clark Spring**s** has very high transmissivity. The amount of water available in the aquifer for surface and groundwater flows is very sensitive to recharge by rainfall. Water flowing through the aquifer is generally water that falls during the wet winter months, although summer rainfall can help prolong the aquifer decline that occurs every summer. The system drains relatively rapidly and water

stored by the aquifer is gradually released in the following few months, rarely carrying over or being stored through the following year. It should be noted that more water flows through the aquifer, and Rock Creek, during the wet winter months than in the summer months, primarily due to the rainfall that occurs in the late fall and winter.

The City of Kent does not have the ability to capture and store the higher flows of winter water at the present time. The highly transmissive aquifer in the Clark Springs area is not useful for storing water that could be used during low flow periods. Any groundwater not used for supply remains in the aquifer and continues on in a westerly direction, or surfaces as surface flow and travels to the Cedar or Green River.

#### 3. Variable, limited, and undefined amount of water through Clark Springs – not stored, pass through

As described above, despite significant analysis and study of the Rock Creek basin, there remains some level of uncertainty about the aquifer in the area, and the influence that it has upon surface and groundwater flows in the basin. This is due to a number of factors that create significant variability and uncertainty in predicting exactly how the aquifer will react to certain conditions. The modeling and analysis performed by Kent has certainly helped to better understand this variable and often misunderstood drainage, and has provided more certainty in understanding and predicting the response to different changes and variations in the areas environment. The continued collection and analysis of data may enhance the ability to better forecast response and effects of changes in the environmental conditions in the basin.

### F. Kent has no jurisdictional control in watershed except for Clark Springs

The City owned parcel in which the Clarks Springs water source is located is the only part of the watershed where the City has jurisdiction. The remainder of the watershed falls under the jurisdiction of King County, except for a small portion on the west side of the watershed located within the City of Maple Valley. Anything that occurs outside of the Clarks Springs property may also fall under the jurisdictions of a state agency depending on the proposed activity. The City of Kent has been, and will continue to comment on projects that may have an impact on groundwater resources in which the City has a vested interest.

## III. Description of Clark Springs Property

### A. Ownership

The City of Kent formally purchased the property known as Clark Springs on November 9, 1954. On March 18, 1969, the property was annexed into the city for municipal purposes by ordinance number 1590.

### B. Boundaries/Location

The Clark Springs source is approximately 320± acres in size and is located near the Kent-Kangley Road, just east of the Maple Valley-Black Diamond Road in the 245$^{th}$ block. Generally the property is located in the South ½ of Section 25, Township 22 North, Range 6 East, W.M. The site is segregated by Kent Kangley Road and by Rock

Creek. Rock Creek flows through the property in a westerly-northwesterly direction. The water intake facilities which are located in the mid westerly part of the property consist of 3 wells and an infiltration gallery. The combined production capacity thereof is about 7.71 MGD which corresponds to the rights granted under Certificate No. 7660-A.

### C. BPA/easements

The Bonneville Power Administration obtained two easements across the property in 1942. The easements run nearly diagonal from the northeast corner to the southwest corner. The width of the easement is 375 feet. The BPA actively maintains the property within the easement as needed. This maintenance is primarily to control trees and vegetation that will have an impact on the safety and integrity of the high voltage transmission lines. Through negotiations with the City of Kent, the maintenance is usually done mechanically or by hand and BPA has been amenable to not using chemicals for vegetation control within the City of Kent watershed properties. Another easement also runs on the western edge of the property from Kent Kangley to the north property line. This easement is for residential access and sanitary sewer.

## IV. Water Demand Forecast

As a matter of law, Kent has an on-going responsibility to plan for and develop the water supplies necessary to meet its projected demands, as well as to maintain and protect the viability of its existing sources.

Water purveyors are required to update their Comprehensive Plans every six years and submit them to the Washington State Department of Health, the local regulatory agency responsible for the oversight of water systems. The comprehensive planning process includes an evaluation of projected water demands over the next 6 years and a forecast for the next twenty years. Projected water demands are influenced by a wide variety of factors, and can often have dramatic changes over just the 6 year period, and certainly over a 20 year period.

Realized demand within the Kent water system has been volatile over the last decade for a number of factors, some of which include watering restrictions imposed during a drought period, an economic downturn which resulted in an eight percent vacancy rate of Kent's commercial core, and the loss of two of its largest water customers. Although these factors have resulted in a short-term decrease in demand, over the long term these demands may be realized again. Furthermore, with Kent's strong commercial / industrial core, and excellent water quality, additional large water users may locate in Kent. It is the City's responsibility to plan for and develop water supplies necessary to meet these potential demands.

### Water Efficiency and Conservation

The City has placed considerable monetary efforts on water efficiency and conservation. Both of these areas are key, and should be considered, when projecting for future water demands. The efforts the City has expended to date on conservation is the sole reason the

City has not entered into a development moratorium prior to the Tacoma Second Supply water being available.

**Conservation**

The Kent City Council formally adopted a conservation program in 1993. However, the City's commitment to conservation has been demonstrated as far back as 1978. The Table below provides a brief description of known conservation activities that have been performed to date.

| YEAR | DESCRIPTION |
|---|---|
| 2004 - Present | Continued on-going water conservation programs including conservation reminders in City utility bills in 2007 and 2008. |
| 2003 | The Kent City Code was amended with Ordinance No. 3656 which includes a ten percent (10%) discount on storm and surface water utility charges for commercial properties utilizing a rainwater harvesting system. |
| 2003 | The City completed its Conservation Potential Assessment and submitted it to the Department of Health, approved by DOH July 14, 2003. |
| 2001 | Best Management Practices (BMP's) were adopted for the Water Department to promote the conservation and protection of endangered species. |
| 2001 | Ordinance No. 3553 was adopted by the City Council which limited the use of water for landscaping irrigation and lawn sprinkling to odd/even dates and any new water meters greater than three inches in diameter would not be activated for use until after October 21, 2001. The ordinance was only in effect until October 1, 2001. |
| 2000 | The Water Department began an annual leak detection program. With the said program, approximately $10,000 dollars annually will be allocated for consultant leak detection services. It is the Departments goal to have the consultant complete monitoring regularly in order to minimize water losses. |
| 2000 | The City Council adopted a new conservation rate structure that consisted of a two-tiered escalating block rate structure. The rate ordinance also included increased water system development charges. For example, the new 1-inch service connection fee is $1,100 and a 10-inch service connection fee is $195,558. These new rates were effective January 1, 2000. |
| 2000 | The City participated in funding and staffing a one day Water Festival for 1,400 5$^{th}$ and 6$^{th}$ grade students from South King County. The event was co-sponsored by South King County Regional Water Association purveyors and the Covington Water District and has been sponsored by Kent in subsequent years. |

| | |
|---|---|
| 2000 | 75 low flow toilet rebates were processed. |
| 2000 | 56 low water use water rebates were processed. |
| 2000 | 24,000 summer watering calendars were mailed. |
| 2000 | 48,000 water conservation brochures were mailed. |
| 2000 | The City performed water audits on 22 City facilities. Retrofits were implemented in 2002. |
| 2000 | The City is preparing a water audit for the top 20 commercial water users. |
| 1999 | Leak detection tests were performed on the Kent Springs Transmission Main. The tests identified a leak of approximately 55 gpm. The repair methods are currently being evaluated. Once the repair is completed, it will produce an approximate water savings of 0.079 MGD (88 Acre-feet per year) or equivalent to approximately 311 average day demand residential connections (79,200 gal / 254 gal per residential connection). |
| 1999 | 24,000 summer water calendars were mailed. |
| 1999 | 48,000 water conservation brochures were mailed. |
| 1999 | 31 low flow toilet rebates were processed. |
| 1999 | 51 low water use washing machine rebates were processed. An additional 32 low water use washing machine rebates were processed for commercial water users. |
| 1999 | An in-concert with the environment program was presented to 1,800 Junior High students at three local schools. |
| 1998 | 24,000 summer water calendars were mailed. |
| 1998 | 48,000 water conservation brochures were mailed. |
| 1998 | Conservation videos were purchased for the conservation library. |
| 1998 | The City, along with Covington Water District, designed and purchased a “water drop” costume for fairs, parades, and special events. |
| 1998 | The City developed a rebate program for low flow toilets and low water use washing machines. |
| 1998 | Conservation presentations were made at 4 local schools. |
| 1998 | The City co-sponsored an in concert with the environment program to 1,800 Junior High students. |
| 1998 | The City started including water usage history on customer’s water bills. |
| 1998 | The City landscape code was revised to include use of native, low water use vegetation and landscaping water requirements, irrigation system design, |

| | |
|---|---|
| | and performance requirements. |
| 1997 | Seams in the Guiberson Reservoir were resealed. The leakage was reduced from 140+ gpm to 10 gpm or less. This produced an approximate savings of 0.187 MGD (210 Acre-feet per year) or equivalent to approximately 735 average residential connections (187,200 gal / 254 gal per residential connection). |
| 1997 | The Water Department repaired a leak on the Kent Springs Transmission Main estimated to be ±200 gpm. This produced an approximate savings of 0.288 MGD (323 Acre-feet per year) or equivalent to approximately 1,130 average day demand residential connections (288,000 gal / 254 gal per residential connection). |
| 1997 | Mailed 60,000 conservation newsletters to residents and businesses. |
| 1997 | 24,000 summer water calendars were mailed. |
| 1997 | 48,000 water conservation brochures were mailed. |
| 1997 | Conservation videos were purchased for the conservation library. |
| 1996 | The Kent Springs Transmission Main from Armstrong Springs to Kent Springs was replaced with 24-inch ductile iron pipe. This was the final replacement of the original aged and leaking concrete cylinder pipe installed in the 1920's/1930's. |
| 1996 | Mailed 60,000 conservation newsletters to residents and businesses. |
| 1996 | 20,000 summer water calendars were mailed. |
| 1996 | 20,000 water conservation brochures were mailed. |
| 1996 | Conservation videos were purchased for the conservation library. |
| 1996 | Conservation presentations were made at 6 local schools. |
| 1996 | The City distributed 200 conservation kits. |
| 1995 | The City and Covington Water District held a two-day conservation workshop for 28 Kent School District teachers. |
| 1995 | Mailed 60,000 conservation newsletters to residents and businesses. |
| 1995 | 20,000 summer water calendars were mailed. |
| 1995 | 20,000 water conservation brochures were mailed. |
| 1995 | Conservation videos were purchased for the conservation library. |
| 1995 | The City co-sponsored a Water Festival with King County in which there were 2,000 participants. |
| 1995 | The City distributed 500 conservation kits. |
| 1994 | Conservation program presentations were made to 4,200 students (K-6). |

| | |
|---|---|
| 1994 | 18,000 summer watering calendars were mailed. |
| 1994 | 18,000 water conservation brochures were mailed. |
| 1994 | The City distributed 1,000 conservation kits. |
| 1993 | The City Council adopted the conservation program. |
| 1993 | Conservation program presentations were made to 4,200 students (K-6). |
| 1993 | 18,000 summer watering calendars were mailed. |
| 1993 | 18,000 water conservation brochures were mailed. |
| 1993 | The City distributed 1,000 conservation kits. |
| 1992 | The City adopted ordinance #3043, which restructured its water rate to reflect a summer surcharge. |
| 1992 | The Kent Springs gallery transmission pipe was slip lined with HDPE pipe. |
| 1991 | Utility Services Association performed a leak study in the downtown area. After a complete and thorough survey of the downtown area, the consultant found the City system to be in good condition. The leaks found were corrected. This produced an approximate water savings of 10,080 gpd (3 Acre-feet per year). |
| 1990 | Replaced 3,578 feet of the Kent Springs Transmission Main with 24-inch ductile iron main from 168$^{th}$ Pl. SE to ±200 feet west of Armstrong Springs. |
| 1988-1990 | Replaced 20,000 feet of the Kent Springs Transmission Main with 30-inch and 36-inch ductile iron main from SE 274$^{th}$ Street to 132$^{nd}$ Avenue SE. |
| 1986 | The Kent Springs Transmission Main was replaced with 2,384 feet of 36-inch main and 1,070 feet of 30-inch main from 104$^{th}$ Avenue to South 274$^{th}$ Street. |
| 1985 | The Kent Springs Transmission Main was replaced with 6,665 feet of 24-inch and 220 feet of 30-inch water main between 152$^{nd}$ Avenue and 132$^{nd}$ Avenue. |
| 1983 | A new policy providing for connection fee for water service outside the City limits was adopted. |
| 1983 | The Kent Springs Transmission Main was replaced with 4,100 feet of 24-inch ductile iron main from 164$^{th}$ Avenue SE to 152$^{nd}$ Avenue SE. |
| 1983 | The Kent Springs Transmission Main was replaced with 8,000 feet of 24-inch and 2,000 feet of 36-inch ductile iron main between the Guiberson Street Reservoir and 104$^{th}$ Avenue SE. |
| 1982 | The City increased its water rate to $1.64 per 100 cubic feet. It should be noted that said rate was one of the highest in the State of Washington at that time. |

| | |
|---|---|
| 1981 | The City adopted Ordinance #2298, which increased the water rate along with establishing a new rate structure (switching from a declining block structure to a flat rate of $0.82 per 100 cubic feet), established a system development charge on new water service connections, and set new permit fees. |
| 1978 | The Kent Springs Transmission Main was replaced with 152 feet of 18-inch and 781 feet of 24-inch ductile iron main from 164th Avenue SE to ±170 feet west of 167th Pl. SE. |

Kent also recognizes the continued need for long term conservation planning to meet future water demands. The City is a partner in Tacoma's Second Supply Project and entered into a multi-agency agreement with the Department of Health to reduce water demand by 10 percent by the year 2010.

**Unaccounted for Water**

The City has gone to great efforts, and takes pride in the results that have been obtained in lowering the amount of unaccounted for water. As can be seen in the table below, the percentage of unaccounted for water has been reduced from almost thirteen percent in 1993 to below five percent in 2008. At some point in time, a point will be reached where the percentage of unaccounted for water bottoms out, which will be above zero, for reasons such as human error and/or inaccurate meters. None-the-less, Kent will continue to strive to maintain a low percentage of unaccounted for water.

| Unaccounted for Water | |
|---|---|
| Year | Percentage |
| 1993 | 12.89 |
| 1994 | 10.17 |
| 1995 | 12.63 |
| 1996 | 12.18 |
| 1997 | 8.60 |
| 1998 | 8.00 |
| 1999 | 6.80 |
| 2000 | 6.53 |
| 2001 | 4.52 |
| 2002 | 3.80 |
| 2003 | 3.37 |
| 2004 | 3.90 |
| 2005 | 3.53 |
| 2006 | 3.11 |
| 2007 | 4.55 |
| 2008 | 4.36 |

## V. Operational Constraints

### A. Long term constraints based on demand

The City has evaluated 12 plus years of supply data from the recent past, with data from 1992 to 2004, to produce a history of reliable or proven water supply from the City of Kent Water System. By analyzing the 12 plus years of supply data, Kent has been able to develop a record of monthly variations in water supply, and estimate the reliability of those groundwater sources of supply. This period of time included cyclic weather patterns and variability in water system demand, as well as aquifer changes and response to withdrawls.

The monthly and annual reliable supply estimate was then compared to the monthly and annual demand projections from Kent's 2002 Comprehensive Water System Plan, beginning with demand projections for 2005 and progressing yearly through 2043. This is the estimated date of build out for the City of Kent water system as it exists today using a number of factors and estimates in the planning and projection of City growth. Also, it should be noted that because of Kent's large commercial/industrial base of customers, growth in the commercial/industrial area can increase demand significantly as new large customers connect to the water system, or existing customers add new processes and increase demands on the water system. Importantly, it should also be understood that demand and growth will not stop in 2043, but changing business demands and elevated construction/density of buildings will cause continued increases in demands, albeit at a slower rate than earlier projections up through 2043.

This comparison has shown that in 2005, the Kent water system supply is lagging behind projected demands by approximately 10 to 20%, spread evenly throughout the year. Reoccurring years of drought, declining aquifers, well failures, water right limitations, and other constraints have limited the system supply in the past five to ten years. Through aggressive conservation, mandatory watering restrictions, and careful management of existing water supplies, as well as an unanticipated downturn in the economy and the resultant commercial building vacancy rates, Kent has been able to meet the system needs without the purchase of emergency water in all but the worst years of drought.

**Over-Pumping**

One concern with using the analytical approach cited above is that there have been years when deep aquifers have been over pumped to meet the system demands. Often it is necessary to rest or lessen the pumping from these aquifers for one to several years to allow them to recover, shifting the demand to other sources. In other instances, wells have been historically pumped harder in the summer months and then allowed to recover through the winter and spring months to be recharged for the next summer months demands. To meet the future demand needs by shifting water supply timing and also to meet the proposed mitigation measures, it may be necessary to pump a well harder in the fall and winter months and then again in the next year spring season, not allowing full recharge of the aquifer, with the resultant lessening of water supply reliability.

**Tacoma – Second Supply Project**

The City of Kent is planning for the completion of the Second Supply Project (SSP), which began construction in 2000, with the final installation of the associated transmission pipeline, water treatment; water storage and up-stream fish passage components, in 2008, at which time the SSP partners in the project will be able to store their share of project water in the reservoir behind the Howard Hansen Dam. Kent's share of storage and transmission capacity is approximately 3,850 acre feet, or 12.64 mgd in the period from June through September. Because the down-stream fish passage facility, the facility required to move fish through the dam, has not been completed by the US Army Corps of Engineers, the partners have a practice of providing half of their stored water (1,925 acre-feet for Kent) to the resource agencies for the benefit of fish. It is anticipated that this practice will continue until the down-stream fish passage facility is completed and operational. However, this is a negotiated agreement each year, and there is no certainty that the arrangement will continue indefinitely. Also, the US Army Corps of Engineers has determined that it will need additional funds ($172 million) for completion of the downstream fish passage facility, and is seeking a source for those funds at the present time.

In January 2009, during a high pool behind the dam, multiple depressions were discovered on the abutment. An analysis needs to be performed by the Corps to identify necessary repairs to the dam/abutment. The US Army Corps of Engineering has made preliminary estimates of 10 years to make permanent repairs to the dam infrastructure.

An analysis of more than 20 years of historical turbidity levels in the Green River system by Tacoma has shown that the months of July and August never have had turbidity events that would make this supply unusable because of turbidity levels above 3.5 Nephelometric Turbidity Units (NTU). The months of June and September are more marginal, with periodic instances of unusable water supplies because the turbidity levels are high enough to create uncertainty about the effectiveness of the disinfection, or cause customer concerns due to turbidity levels.

For the benefit of Tacoma's direct end customers, the Tacoma Green River Supply System, under Tacoma's first diversion water right, is designed to mix highly turbid surface water from the Green River when it exceeds 3.5 NTU before it enters Tacoma's water distribution system. The Department of Health has set an MCL threshold of 5 NTU for water entering a distribution system, and the 3.5 NTU trigger that Tacoma uses allows a safety cushion for the water system to prevent them from becoming non-compliant and being required to issue a boil water notice to their customers. In contrast to the City of Tacoma's customers, the water supplied to Kent as part of the SSP does not have access to the water used for dilution and/or blending by Tacoma (under its first diversion water right), therefore Kent can only use water from the SSP and second diversion water right system when turbidity levels stay below 3.5 NTU. The months of October through May are historically much more likely to have significant turbidity

above 3.5 NTU, that will preclude the use of SSP water by Kent as a reliable source of supply during those months.

Although turbidity levels have not historically been an issue during the month of August for the Green River supply, taste, odor, and color issues have been realized in recent years. Storing water behind the dam in the late winter and spring to create a usable water supply during the summer is the desire of Kent to receive summer water and meet its peaking demands. When the pool was filled behind the dam over the last several years, it has been a reoccurring issue that the increase in water temperature, stratification of the pool, and flooding vegetation around the edges of the pool cause an increase in organic material in the water resulting in taste concerns and an increase in the level of manganese. The manganese causes the water to appear yellow in color and has exceeded the secondary maximum contaminant levels at times. These taste, odor, and color issues, depending on the severity, are often unacceptable to Kent customers, and have caused Kent not to use Green River water during the months of August and September at times.

### B. System wide constraints – timing sources to provide more water at Clark Springs.

As described in earlier paragraphs, the City of Kent supply demands are based on annual yield projections from Kent sources based on historical supply quantities. All water rights and claims in the State of Washington are based on annual and instantaneous consumption, beginning with each new year. As such, many of Kent's sources are constrained by the annual yield of water up to the water right quantity of the individual source. As more of the source water is used to meet demands earlier in each year, less of the remaining water can be used for fall and winter demands. In a similar fashion, sources with a limited quantity of water available, constrained by source capacity, would be used to meet the initial demands of the water system, and then be allowed to rest and recover their capacity for the following season. Without careful analysis and data gathering over a number of years to predict what effects will be under adverse conditions, there is inherent risk with attempting to shift water withdrawals to periods that are unproven and have the potential to reduce reliability and yield of any given source. A factor noted earlier is that the other deeper aquifers are generally less susceptible to seasonal rainfall variations. However they are mostly located in areas of significant development within the urban growth boundary, and appear to be influenced by growth related external factors. These factors would include issues such as declining aquifer recharge rates exacerbated by paving and other impervious surfaces created by development and growth, and by other users withdrawing significant amounts of water from the aquifer, lessening the reliability of those groundwater sources over the long term.

### C. Clark Springs constraints

As described in 2.E Hydrology, the Clark Springs is dependent upon rainfall recharge in a specific pattern to produce the yield that would allow for flow augmentation. A unique characteristic of the Rock Creek aquifer that constrains the Clark Springs operations is the very high aquifer transmissivity which does not allow storage of groundwater. Peak

annual precipitation leaves the aquifer in a matter of months, though Rock Creek is a perennial stream from approximately the eastern boundary of the Clark Springs property. Another constraint is the unique groundwater divide that shunts a significant portion of the groundwater out of the basin to drainages other than Rock Creek. Each of these reduce or constrain the quantity of water available in a reliable fashion for the operation of the Clark Springs supply and future flow augmentation facilities.

## VI. Meeting Demands

As a matter of law, Kent has an on-going responsibility to plan for and develop the water supplies necessary to meet its projected population growth, as well as to maintain and protect the viability of Kent's existing sources. Within recent years, however, meeting these responsibilities has become a significant challenge due to a combination of factors that include: the seasonal and development-based impacts on source aquifers; the increasingly stringent and dynamic regulatory environment governing water supply, water quality, and water rights, and the implementation of the Endangered Species Act in an urbanized setting. The State's Growth Management Act also limits development by requiring cities to have adequate water supplies prior to additional development.

In 2003, the Municipal Water Law (MWL) was passed by the Washington State Legislature. The MWL had several objectives which included:

- Providing greater certainty to municipal water suppliers regarding the legal status and use of their certified water rights;
- Resolving past regulatory ambiguities regarding the definition of municipal water suppliers and municipal purpose water rights;
- Revising and prescribing the manner in which municipal water supplier service areas are to be described in water system plans;
- Defining the scope of duties and obligations of municipal water suppliers within their retail service areas;
- Providing greater flexibility to how much municipal purpose water rights may be used within the service areas of municipal water supply systems; and
- Prescribing new water conservation and water use efficiency responsibilities and reporting requirements.

In June 2008, portions of the MWL relating to the definitions section (RCW 90.03.015)(3)(4), and the status of inchoate certificated municipal rights (RCW 90.03.330)(3) were struck down by King County Superior Court. This action occurred pursuant to a facial constitutional challenge brought by Tribes and environmental groups. This King County Superior Court decision was appealed by all parties in July, 2008 to the Washington State Supreme Court. Given this situation, Kent's ability to meet its current and future projected demands is in jeopardy.

In its efforts to meet the challenges posed by both the natural and regulatory environment, Kent has made, and will continue to make, significant investments in conservation, source rehabilitation, and the development of new sources of supply as

summarized below. It is expected that the development of new sources will not change the City's reliance on the Clark Springs system for their water supply needs.

### A. Surface Water

The Green River and Cedar Rivers are subject to minimum instream flow rules and/or agreements that effectively preclude all new surface water withdrawals beyond those occurring during high flow winter months. Since the City of Tacoma secured a flow-restricted, seasonal water right on the Green River for its Second Supply/P-5 project in the 1980's, no further surface water applications have been approved by Ecology due to on-going concerns relating to flow levels, cumulative impacts, and tribal treaty rights. Moreover, because streams tributary to the Green and Cedar Rivers have been closed by administrative rule to further appropriation, Ecology has not entertained the issuance of new primary rights for these surface waters for several years. Due to the foregoing factors, and the Endangered Species Act, development of new surface water rights is not considered a reasonable or viable supply alternative.

### B. Acquisition of Existing Rights

State water law allows the transfer of existing rights to new places of use and purposes of use if such actions do not impair existing rights and do not create new, adverse effects upon pre-existing aquatic habit, flow, and water quality conditions. Given the difficulty in securing new ground and surface water sources within the Green River basin, Kent has explored the potential of securing existing water rights within the vicinity of its service area that are still valid and could provide water of sufficient quality and quantity to be of value to the system.

With the exception of a defunct trout farm with a highly questionable water right, no water rights could be identified within a reasonable distance of Kent's service area which were still active and/or not subject to relinquishment due to lack of use. This alternative is therefore not considered a reasonable or practicable alternative to Kent's supplyneeds.

### C. Water Right Changes

Water right changes include a variety of options, including changes in place of use, purpose of use, and to the point of diversion or withdrawal of water, as well as the addition of points of diversion or withdrawals. Although Kent has evaluated several options for water right changes, they are uncertain at best, and none of them are considered a reliable source of future water supply.

### D. Regional Supply Purchases

Assessing the viability of acquiring water supply from adjacent and regional supply systems has been a constant feature of Kent's water supply planning and system operations. In the past the City has acquired firm, annual supply, via existing interties, from the cities of Tukwila and Renton, and Highline Water District (Water District 75). However, because of demand occurring within the respective service areas of these cities/systems, the provision of supply has been suspended or limited to emergency supply.

Aside from the systems described above, Kent has examined opportunities with other regional purveyors to acquire new, firm, annual supply. That investigation has focused on the City of Auburn, City of Tacoma, City of Seattle and the Cascade Water Alliance.

**Seattle Public Utilities (SPU)**

In the past, SPU has approached Kent to discuss the opportunity and terms under which Kent could secure a bridge supply of water that could assist Kent in meeting its summer peaking needs until the P-5 project is on-line and providing water to the Kent water system. In addition, Kent constructed an emergency intertie with Soos Creek Water and Sewer District that provides the opportunity to receive Seattle water via bridging across Soos Creek's distribution system. However, the Seattle water supply is heavily dependent upon snowpack, which may be influenced by future climate change; and with long term obligations to existing Seattle customers and other water purveyors, Kent does not anticipate an opportunity for long term supply from Seattle. There may be potential for Kent to partner with Seattle and others in future regional supply development projects, as partnerships are able to determine that the projects are necessary and cost effective, and funding becomes available.

**Cascade Water Alliance**

The Cascade Water Alliance (CWA) is a consortium of King County cities and water districts. Its members include the City's of Bellevue, Issaquah, Kirkland, Redmond, Tukwila, Covington Water District, Sammamish Plateau Water and Sewer District, and Skyway Water and Sewer District. The CWA was formed in response to SPU's notice that it would not renew its current agreement to existing customers in 2012. Shortly after its inception, the CWA commenced negotiations with SPU to assume responsibility for the distribution of SPU water to the purveyor community post – 2012.

The CWA is pursuing the Lake Tapps water right currently held by Puget Sound Energy. This transfer of water right ownership and use is currently being challenged in the court system. Even if the CWA is successful in obtaining the water right, no domestic water is anticipated from this source until the mid 2020's. With the CWA's dependence of purchasing water from other utilities, it is not considered a potential source of supply.

In October of 2005, the CWA executed a wholesale water agreement with Tacoma Public Utilities. The agreement contains provisions whereby CWA is obligated to take or pay for volumes of water from Tacoma starting January of 2009. CWA deferred construction of their regional supply pipeline that was to move the Tacoma water and approached the City of Kent in the fall of 2008 to wheel its Tacoma water through the Kent system to the City of Tukwila. No wheeling agreement has been reached between CWA and Kent.

**City of Auburn**

The City of Auburn is located directly south of Kent. Based on its Water System Plan (1995) Auburn has sufficient water supplies to meet projected demand until 2015. In 1996, Auburn executed interruptible supply agreements with two adjacent systems

(Covington Water District and Water District 111) totaling 1-5 mgd. Under the terms of this agreement, should Auburn succeed in securing new primary water rights, the interruptible supplies may be converted to firm supply. If, however, Auburn fails to secure new rights, the water may be called back in 2010 or earlier to meet the City's projected municipal demand.

Unfortunately, Auburn's pursuit of acquiring those new, primary water rights in its Valley Production Aquifer has proven to be unsuccessful. As such Auburn's ability to meet its own future water demand needs, independent of those of its contracting Districts, is in jeopardy.

**City of Renton**

Negotiations had taken place with Renton to acquire 1-2 mgd of interruptible "bridge" supplies. The need for such "bridge" supplies was necessary because the proposed P-5 Tacoma project was not expected to deliver supply on either an annual or seasonal basis. No agreement was reached and negotiations with Renton are no longer underway.

**City of Tukwila**

The City of Tukwila has recently contacted Kent to discuss the possibility of Kent supplying water to Tukwila with the potential to wheel some of the water to other CWA members. Therefore, water availability from Tukwila is not considered a viable option by Kent.

**Lakehaven Utility District**

The Lakehaven Utility District and City of Kent discussed a "bridge" supply through a potential intertie that would provide Kent with an interim supply of up to 2 mgd. The supply would have remained interim until 2008 when flows from Tacoma's second supply pipeline would be available to the City. No action was taken as result of the discussions. However, Kent has submitted a letter of interest in participating in the development of its OASIS aquifer storage project over the next 20 years.

**City of Tacoma: Second Supply Pipeline Project (P-5)**

The P-5 project would provide Tacoma with a second supply pipeline and divert water from the Green River for local as well as regional benefit. The P-5 water right is subject to strict instream flow limitations and other requirements set through negotiations with the state and federal agencies and the Muckleshoot Indian Tribe. Accordingly, it can not presently provide reliable, firm annual supply. Kent executed its final agreement to receive P-5 supply in 2000. In 2008, the City of Kent tested metering and conveyance facilities connected to the Second Supply Project. However, use of this source is constrained due to those factors stated in Section V of this appendix, Tacoma – Second Supply Project.

In 1985 Kent contracted with Tacoma Public Utilities (TPU) to purchase 7.2 mgd of summer peaking water from the proposed Pipeline 5/Second Supply project. This volume was increased to 12.64 mgd in 2002 when Kent agreed to purchase ¼ of Seattle's

share after Seattle was no longer a participant in the project. The remaining portion of Seattle's share was purchased by other participants in the project. To this end, and in reliance on the Ecology-approved water right and place of use documents issued to Tacoma, Kent has expended substantial financial resources on the P-5 project. The P-5 source of supply is considered critical to Kent's ability to meet near and long-term demand needs, with some constraints that may limit the availability of the water supply at times.

## E. Conservation

### Enhanced Conservation Measures

Kent's Conservation Program Demand Management (DM) practices, including water conservation, inclining rate structures, public education, distribution of water saving devices (e.g. low flow shower heads and sink aerators), program incentives and leak detection can play an important role in prolonging use of existing water supplies and delaying the time when new source is required. To that end, in 1993, Kent and other South King County water systems adopted and implemented an aggressive and comprehensive conservation program to prolong supply and mitigate peaking demands that place stress on available sources. The program includes the following components.

- block rate structure
- seasonal rate pricing/summer conservation rates
- water shortage emergency/regulation which authorize the Mayor to restrict non-essential public uses and levy fines during drought condition
- public education/promotional materials
- single/multi-family conservation kits
- metering for all customers
- distribution of water efficient plumbing fixtures
- leak detection
- water efficient irrigation technology
- conservation specialist
- drought tolerant landscaping
- rebate programs

To determine the opportunity to secure further conservation gains, Kent examined the costs and feasibility of installing low flow toilets and shower flow restrictors in all residential connections. The number of residential connections for the year 1991 was the figure used as it was prior to the date the water efficient fixture/plumbing code went into effect. Based on 7,422 residential connections in 1991, at a savings of 33.5 gallons/day per residential connection, the daily reduction in water productions from installing the efficiency measures cited above was estimated to be 248,637 gallons/day and/or 90.753 mg/yr. Using an estimate of $1,000 per connection for retrofit, the cost of such a program was calculated to be approximately $7.5 million. While such a program offers further benefits, it is not considered cost-effective at this time.

As alternative enhanced conservation measures, Kent developed a commercial/industrial customer water audit program of the top 20 users and adopted a revised inclining block rate structure. Kent believes that the new rate structure should increase water use efficiency on an annual basis, including summer peaking months. As a result of the audit findings, the City implemented a commercial/industrial rebate program for replacing old inefficient equipment and facilities.

Kent is a nineteen point four percent (19.4 %) partner in Tacoma's Second Supply Pipeline Project. When the Department of Ecology extended the Second Diversion water right, a ten percent (10 %) reduction (conservation) in water demand by 2010 condition was placed on all of the project participants (Tacoma, LakeHaven Utility District, Covington Water District, and Kent). Kent is committed to reducing water demand by ten percent (10%). Reports are given to the Department of Ecology and Department of Health every two years by the project partners to provide updates on the status of meeting this requirement.

In an effort to meet the 10% water conservation goal identified in the Tacoma Second Supply Project, the City of Kent in June 2003, through its consultant Economic and Engineering Services, Inc., completed a Water Conservation Potential Assessment that analyzed the potential water savings and associated costs for conservation measures that could be undertaken between the year 2003 and 2010. The conservation measures identified in the report are in addition to those measures the City had already been implementing. For additional information on the water conservation in the City of Kent, please refer to the attached Water Conservation Potential Assessment.

**F. Aquifer storage and recovery**

The viability of ASR is subject to many factors, not least of which is the presence and availability of suitable aquifers. In the Puget Sound area, these characteristics are:

- High aquifer transmissivity to permit rapid recharge and recovery;
- Deep aquifer, to provide storage capacity and hydraulic separation from surface waters;
- Good aquifer confinement by aquitards to reduce the loss of stored water;
- Aquifer storativity and depth to water, to provide sufficient aquifer storage capacity; and
- Compatible water quality between aquifer and recharge waters.

A primary limitation in the Puget Sound area in general, and around the City of Kent in particular relative to ASR, is the limited presence of aquifers that are suitable for recharge and recovery. In general, most groundwater resources in the region are drawn from aquifers of shallow or intermediate depth (typically less than 200 feet below the surface).

The contrast in precipitation and recharge between winter and summer means that many shallow or intermediate aquifers are heavily drawn-down during the peak demand periods

of the summer months when groundwater levels naturally decline. However, these shallow aquifers are seasonally replenished through natural recharge and are typically discharging to surface water via springs and streambeds by the late spring. Any additional water artificially recharged during the winter months would merely hasten the natural rise in groundwater levels to the point where the aquifers overflow, new seeps and springs emerge, and the bulk of the recharged water is lost as winter runoff through local surface water discharge.

Due to winter precipitation, this increased aquifer discharge would occur around the time of the spring runoff, when streams are already swollen (Ecology et al., 1995). The potential benefit of artificial recharge during the winter months, that is to raise aquifer levels in summer, or to help offset impacts to minimum instream flows, would thus not be realized. The artificial recharge of shallow or intermediate aquifers in the area of Kent will therefore achieve very little in terms of increased water supply. Winter groundwater levels elevated by artificial recharge would also pose an increased threat to the stability of sensitive potentially unstable slopes in the area.

**Soos Creek Well Artificial Recharge**

Kent has determined that a small opportunity for ASR may exist at the site of its Soos Creek Well. This well, which is drilled to a depth of 431 feet (approximately sea level), taps into one of the deeper Qc(3) aquifers which are confined but of unknown lateral extent. Production rates from the well have been limited within recent years to only half of the original permitted amount. The main factor in the impaired yield is a long-term lowering of the static water level within the aquifer, which has reduced the available drawdown at the Soos Creek Well.

The aquifer may be affected by additional extraction wells, which are causing an overdraught. Recharge to the confined aquifer is also limited by the hydraulic characteristics of the confining layers, which may impair the aquifer's ability to fully recover from each period of groundwater pumping during the summer months.

To address this problem, Kent budgeted $80,000 to study the feasibility of restoring the aquifer's production capacity by diverting and injecting winter flows from its Clark Springs source. If successful, this action could potentially increase Kent's supply by approximately 0.5 MGD. While this amount is not insignificant, it falls short of the amount required to enhance overall system reliability.

**Lakehaven Utility District**

In 2004 the City of Kent submitted copies of the majority of its water rights to LakeHaven Utility district to be included in LakeHaven’s Optimization of Aquifer Storage for Increased Supply (OASIS) project on the Mirror Lake aquifer. Water stored from Kent’s sources in the aquifer would be available to Kent in the future when the demands required.

## G. Desalination

The following information on desalination was prepared for the City by Kennedy/Jenks Consultants in March of 1998.

Desalination is a water supply alternative that is becoming more widely used as high quality fresh water supplies grow increasingly scarce. Desalination makes available a nearly unlimited source of water by treating seawater for potable use. Use of seawater from the Puget Sound does not require a water right. Therefore, ample seawater is available to meet the long-term demand or reliability standard as long as the treatment process is designed to handle the flow.

Two different membrane processes are applicable to desalination: pressure driven and electrical driven. Pressure-driven processes include RO, nanofiltration, ultrafiltration, and microfiltration. Electrical-driven processes include electrodialysis and its variant, electrodialysis reversal. Generally, RO is the preferred process for desalination (AWWA Water Resource Conference Readings 1997). Filtration processes cannot remove dissolved solids (e.g., chlorides) nearly as effective as RO. Electrodialysis system do not provide barriers for dissolved organics and microbiological contaminants, nor are these systems as efficient as RO at treating water with a high amount of total dissolved solids (e.g., seawater from the Puget Sound). For these reasons, it was assumed that desalination would be accomplished with RO.

The treatment scheme for desalination includes seawater pumping, pretreatment, filtration, prefiltration, RO, and product water treatment, followed by distribution (Desalination 1989). Seawater could be pumped directly from Puget Sound for treatment. A desalination plant could potentially be located within Redondo or Salt Water State Park, both which are adjacent to Puget Sound. Pretreatment consists of screening, coagulation, and flocculation to reduce the turbidity of the feed water. Filtration and prefiltration involve the use of multi-media filters are microfiltration, respectively, to decrease the total suspended solids in the feed water, thereby preventing undue fouling of the membranes. The RO process employs high pressure pumps [up to 850 pounds per square inch (psi)] to remove dissolved solids by passing the feed water through semi-permeable membranes. Following reverse osmosis, the product water is disinfected to kill pathogens that were not removed by RO. If necessary, additional product water treatment may be included to improve taste and odor.

Although Desalination could meet the future demands with a continual supply not limited by contracts or regulations, this alternative is simply too expensive to justify further consideration.

## H. Water re-use

### Wastewater Reuse

The following excerpts on wastewater and stormwater reuse were prepared for the City by Kennedy/Jenks Consultants in March of 1998.

The City of Kent currently disposes of over 3 mgd of wastewater (based upon projected population of 50,416 for 1998 and typical water use of 60 gallons per capita per day) to King County Metro's East Division Wastewater Treatment Plant in the City of Renton (Renton WWTP). In addition to the high cost of this alternative, there is serious question as to its feasibility. Although enough reclaimed water may be available for injection into the City's Clark and Kent Springs aquifer systems to meet demand, it is uncertain whether the same quantity of water could be withdrawn from the aquifer.

A significant amount of reclaimed water injected into the aquifer systems is likely to leak out of the capture zone of the springs. In short, there is no way to ensure that recharging the aquifers would allow increased withdrawal to meet demands. The viability of this alternative is largely dependent upon the suitability of the aquifer for water storage and extraction. Because of the high cost of this alternative and the uncertainty with the suitability of the aquifer, this alternative is not considered feasible.

**Stormwater Reuse**

Stormwater runoff and overflow was evaluated as a source of potable water to meet future demands. The City of Kent operates a large stormwater treatment system that collects runoff from approximately 830 acres of developed area within the City and overflow from Mill Creek to control flooding and erosion downstream. The City's stormwater treatment system consists of constructed wetlands designed to remove urban pollutants, followed by a detention lagoon. Treated runoff and overflow are then discharged back to Mill Creek under controlled release rates.

Effluent from the stormwater treatment system would be viewed as surface water in regards to treatment for potable water. DOH regulations require that surface water be coagulated, filtered, and disinfected to meet the appropriate water quality criteria (Chapter 246-290 WAC). Because these are essentially the same treatment requirements as reclaimed water for non-potable use (with additional disinfection for a greater reduction of pathogens), there would be little savings in cost by treating water separately for potable and non-potable demands. Furthermore, the added cost of a separate distribution system would far exceed any treatment cost savings. Therefore, it was assumed that all water would be treated for potable use and discharged into the existing distribution system.

**System Requirements**

Kent's existing stormwater treatment system relies on wetland vegetation to remove pollutants from stormwater runoff. Many waterfowl also rely on the wetlands as a wildlife refuge. Therefore, impact on the wetlands must be minimized to maintain an effective treatment system and a stable wildlife habitat. The vegetation and wildlife cannot be subjected to large fluctuations in the water level of the wetlands. Consequently, it would not be possible to withdraw water directly from the stormwater treatment system because wide variations in demand, which are common with potable water, could significantly impact the water level. In addition, the City's stormwater treatment system has insufficient storage to meet the reliability standard under any of the

scenarios. Therefore, a separate stormwater detention basin would need to be constructed to provide in excess of 5,000 acre-feet of storage for the collected stormwater in order to protect the wetlands and meet the reliability standard.

## I. Education

The City of Kent provides environmental educational opportunities to our citizens. Though not all educational programs and opportunities provided by the City of Kent are directly related to water, they do foster greater environmental awareness and stewardship of environmental resources. Educational opportunities provided by the City include but are not limited to:

- Annual water festival for over 2000 4th – 6th grade students which exposes students, teachers and parents to various issues related to water resources. This include but is not limited to: supply, wastewater, wetlands, water cycle, conservation and habitat for aquatic and terrestrial species.
- The City of Kent has completed newsletters and the annual Consumer Confidence Report for the water supply. These include information on water conservation and protection of groundwater resources.
- The City is in the process of developing a comprehensive environmental resources document which will describe natural resources in Kent and the importance of those resources to the community. This will include a brief natural history, water resources and habitat related issues.
- City staff have in the past have visited classrooms to discuss natural resources. These visits have included potting and planting 2000 trees throughout the city and school yards. Staff presentations to classrooms have also included topics related to groundwater, development, salmon and the Green River Natural Resources Area.
- The City provides opportunities for citizens to volunteer throughout the city where they also learn about water resources, conservation and habitat. These volunteer projects are typically associated with a planting event at the Green River Natural Resources Area, along a stream or in a park within the City.
- Departmental planting events have occurred in the past where staff plants trees along a riparian corridor to provide a net gain for water resources in the City. Often times citizens inquire about the projects giving staff a chance to educate the citizens.
- Staff has appeared on the government access channel to discuss various topics related to the environmental issues including water conservation, rebate programs and stormwater.
- The City of Kent Parks Department also provides volunteer planting and education opportunities.
- The City participates in regional watershed education/public involvement via the WRIA process in the Green and Cedar River basins.
- Staff provides comments during the development process to jurisdictions within the City's Wellhead Protection Areas. These comments request that the jurisdiction require a note to be placed on the face of plats and short plats

that they are located within a Wellhead Protection Area and provides numbers to call for additional information.

The City is dedicated to continuing public education regarding environmental and natural resources issues.

### J. Wellhead Protection

The City of Kent completed a Wellhead Protection Plan (WHPP) in 1996 for the Clark, Kent and Armstrong Springs Sources. This plan was completed in conjunction with the Covington Water District and King County Water District #111 who simultaneously completed WHPPs. The Plan has been adopted by Kent City Council via Resolution 1563 on February 15, 2000.

The City of Kent hired a Wellhead Protection Engineer in 1999 to implement the plan. Since that time the City has been actively implementing the program and establishing relationships with various regulatory agencies throughout the area to protect the regional water supply. Activities have included notification to potential contaminant sources, commenting on the proposed development within wellhead protection areas, review of Landsburg Mine and beginning the development of an Integrated Pest Management Plan. Ongoing plan implementation and updates to the WHPP will continue in the City of Kent.

### K. Drilling replacement wells

The City's water department has been and will continue to monitor production for all the City's production wells. Due to the general use of wells over time, they have a tendency to decrease in the production as a result of becoming clogged with finer materials. To maintain production levels of the wells, the City has in the past re-drilled wells. Re-drilling wells helps to maintain current levels of production and reliability but does not result in a significant increase of well yields.

## VII. Flow Augmentation Constraints

### A. Impact of increased augmentation through another pump or a larger pump

The option of installing larger capacity pump(s) and other infrastructure at Clark Springs was evaluated as an option for increasing the capacity of the flow augmentation infrastructure presently in operation at the Clark Springs facility. However, through careful evaluation and based on the modeling performed of the surface and groundwater availability in the area of the Clark Springs facility, any flow withdrawn from the infiltration gallery reduces the quantity of water available to the City for supply by an equal amount. Therefore the limiting factor in the augmentation quantity is available supply and not the mechanical equipment capacity.

### B. Finite amount of water through Clark Springs

As described previously in section 2.E Hydrology, the quantity of water available for flow augmentation in the fall and winter months of October, November and December is constrained by precipitation timing and quantity, which affect aquifer levels and

groundwater flows. The "flow through" aquifer found at Clark Springs is highly transmissive and has no storage capacity, and as withdrawal methods do not remove all of the water passing through the aquifer in that area, a significant percentage of the water remains in the aquifer and passes on through to the aquifer west of Clark Springs.

### C. Precipitation driven system

As described previously in section 2.E Hydrology, and above, the precipitation of the Rock Creek basin directly influences the quantities of water available as groundwater, for supply withdrawals and any augment withdrawals.

## VIII. Conclusion

Maintaining the Clark Springs source is vital the public health and safety of Kent's customers in addition to maintaining the economy of the City. To help meet these needs the City has been proactive in maximizing efficiency of the existing system as demonstrated by the extremely low unaccounted for water, re-drilling of replacement wells to regain lost productivity and intense water conservation, educational and wellhead protection programs. Kent will need to continue to maximize the use of its present water sources while exploring other potential sources of reliable water supply to meet future demands.

# APPENDIX H

## Rock Creek Flow
## Mitigation Proposal – HCM-1

*This page intentionally left blank.*

*Appendix H*

# Clark Springs Water Supply System
# Habitat Conservation Plan
# Rock Creek Flow Mitigation Proposal
# Habitat Conservation Measure 1

***Completed by the City of Kent***
***Public Works Department***

***December 2005***

# APPENDIX H

## Rock Creek Flow Mitigation Proposal
## HCM-1

### I. Introduction

As a part of mitigation measures for the HCP, the City of Kent is proposing to augment stream flows during the critical low flow period of October through December. The City has been voluntarily augmenting flows since 1998. To develop a flow augmentation proposal for Rock Creek, the City of Kent used a scenario that analyzes the two-month antecedent precipitation period relative to the specific augmentation months.

### II. Justification for the Antecedent Precipitation Period

There is no direct surface runoff in the upper basin during the summer, so all streamflow is derived from groundwater discharge leaving the aquifer east of Clark Springs. Available streamflow at Clark Springs in the critical fall months is strongly dependent on the amount of precipitation occurring within the upper basin during the preceding (or antecedent) period of one to three months. As a result, the relative natural flow occurring in Rock Creek at Clark Springs at a given time can be estimated based on the total precipitation occurring in the previous two-month antecedent period. This provides Kent's primary predictive tool for anticipating flow conditions. The two-month period relates to timing and intensity of precipitation, and the time it takes for water to move through three key parts of the hydrologic cycle related to groundwater flow that control natural surface flows in Rock Creek:

1) Summer rainfall must first meet the moisture deficit for surface soils before effective infiltration of significant amounts can occur into the subsurface. Thus the initial rains may only serve to wet the surface soils and must be followed soon by more rain that will provide sufficient excess moisture to drive water downward from the upper soil layers.

2) Within the upper Rock Creek Basin, where the water table is typically between 15 and 50 feet deep, the percolation of moisture down to the water table takes a finite amount of time (hours to a few days).

3) Once moisture reaches the water table and recharges the groundwater, it causes the water table to rise. As the water table rises, it increases the hydraulic gradient towards the Georgetown/Ravensdale area, which in turn increases flows into Rock Creek and through Clark Springs. In the unconfined outwash aquifer in the upper Rock Creek basin, this process takes a few days to a few weeks for the effect of up-basin recharge to become manifest as a change in flow at Clark Springs.

Combining each part of this process, and correlating local precipitation data with streamflow for the historic records available, results in a cumulative time-lag of one to three months between precipitation events and their effect on streamflows at Clark Springs. Conversely in dry periods when there are few if any recharge events in those preceding months, the absence of recharge results in declining flows at Clark Springs as the upstream water table falls and the aquifer drains at a progressively decreasing rate.

## III. Precipitation Data

The evaluation of precipitation in the Rock Creek basin was completed using 74 years of data (1931-2004). Monthly and annual precipitation data was available from the WA Climate Data Center, and daily precipitation was available from the Western Regional Climate Data Center, all of which was collected at Landsburg. The data is currently being collected by the City of Seattle Public Utilities (SPU). Landsburg is located approximately one mile north of the northern boundary of the Rock Creek basin near the Landsburg Road crossing of the Cedar River. The close proximity of the data collection point to the Rock Creek basin, and the length of time that the precipitation has been collected, allowed for a significant analysis of precipitation and recharge trends. This assisted in the development of a means to correlate above or below normal precipitation patterns in the basin (i.e. wet, normal, dry, and drought) with the functional patterns of Rock Creek and the Clark Springs water supply.

## IV. Methodology

The Landsburg monthly and annual total precipitation data was transferred into a spreadsheet which allowed the data to be easily viewed and evaluated on a mid-month, monthly and annual basis for the 74 year period (see Table A). The data gaps in the table during the months of July through November were evaluated for the possible impact upon the results of the analysis. The months with missing data from the WA Climate Data Center and the Western Regional Climate Data Center were identified by letters, as indicated in the included description on Table A. For those data gaps larger than 5 days in a month, the monthly data has been eliminated by the City from the available database, and Kent chose to eliminate those periods from their analysis as well in order to prevent shifting of the data averages (see Table A for months that were eliminated).

The two months of antecedent precipitation data were added together to identify values for precipitation periods of July 16-Aug. 15, Aug. 1-Sept. 30, Aug. 16-Oct. 15, Sept. 1-Oct. 31, Sept. 16-Nov. 15 and Oct. 1-Nov. 30 The antecedent precipitation period is defined as the two month combined precipitation total prior to the monthly periods proposed for augmentation, based on the most recent precipitation information (wet/dry periods). Based on the 74 year precipitation record at Landsburg, and removing the months within the antecedent precipitation periods where more than five days of data was missing, a mean precipitation was developed for each antecedent precipitation period (see Table A). A two week lag has been built into the precipitation and augmentation analysis sequence to allow for data collection and decision-making coordination among staff and outside agencies. The lag would be between the antecedent precipitation period and the beginning of the semi-monthly augmentation period.

RCW 43.83B.400 – states that a "drought condition" means that the water supply for a geographical area or for a significant portion of a geographical area is below 75% of normal, and a water shortage is likely to create undue hardships for various water uses and users. The Rock Creek basin, for municipal water supply purposes and for instream flows, is dependent on recharge from precipitation. The City is proposing the use of 50% of normal precipitation as the criteria to identify a drought, which is a more conservative or onerous criteria than the definition in the RCW, and thus is proposing a higher commitment for instream flows during drought conditions.

Hydroclimate probabilities used by HDR in the final draft of the Transmission and Supply Plan (TSP) prepared for the Cascade Water Alliance were also compared in the analysis. Within the TSP, three hydroclimate scenarios were considered when evaluating the reliability for the Lake Tapps supply– normal, dry, and drought. The dry scenario was defined as having a percent exceedence of precipitation with a range of 75% (1 in 4) to 85% (1 in 6.5) and the drought scenario was defined as having a percent exceedence with a range of 90% (1 in 10) to 99% (1 in 100). The normal, dry, and drought probabilities proposed by Kent are comparable to those proposed by the Cascade Water Alliance.

Kent proposes to use the two month antecedent precipitation value compared to the average precipitation as follows: >125% will be classified a wet period, 75%-125% a normal period, 50%-75% a dry period and <50% a drought period. The type of antecedent precipitation as defined above will determine the augmentation flow commitment within the HCP. Using the mean precipitation for each two month antecedent precipitation period from Table A, wet, normal, dry and drought precipitation ranges were calculated. The data is shown in Table B.

**Table B – Precipitation Ranges (in inches)**

| Antecedent Precipitation Period | Mean | Wet (>125%) | Normal 75%-125% | Dry 50%-75% | Drought <50% | Years of Data | Augmentation Period |
|---|---|---|---|---|---|---|---|
| July 16-Sept 15 | 3.61 | >4.51 | 2.70 - 4.51 | 1.80 - 2.70 | 1.80 | 70 | Oct 1 - Oct 15 |
| Aug 1-Sept 30 | 4.80 | >6.01 | 3.60 - 6.01 | 2.40 - 3.60 | 2.40 | 72 | Oct 15-Oct 31 |
| Aug 16-Oct 15 | 6.17 | >7.71 | 4.62 - 7.71 | 3.08 - 4.62 | 3.08 | 68 | Nov 1-Nov 15 |
| Sept 1-Oct 31 | 8.25 | >10.32 | 6.19 - 10.32 | 4.13 - 6.19 | 4.13 | 70 | Nov 15-Nov 30 |
| Sept 16-Nov 15 | 10.69 | >13.37 | 8.02 - 13.37 | 5.35 - 8.02 | 5.35 | 69 | Dec 1-Dec 15 |
| Oct 1-Nov 30 | 13.24 | >16.55 | 9.93 - 16.55 | 6.62 - 9.93 | 6.62 | 69 | Dec 16-Dec 31 |

Precipitation ranges from Table B were applied to antecedent precipitation periods to create Table C (attached). Those periods represented by values greater than 125% of the mean were color coded green for wet periods, those between 75% and 50% of the mean were color coded yellow for dry periods, and those with less than 50% of the mean precipitation were color coded red for drought periods. All other precipitation values were considered "normal" periods for precipitation, within the range of 75% of the mean up to 125% of the mean. Table D identifies the number of times a wet, dry and drought has occurred since 1931 for each antecedent precipitation period.

**Table D – Frequency of Drought, Dry and Wet Antecedent Precipitation Periods**

| Antecedent Precipitation Period | Mean | Wet >125% | Normal 75%-125% | Dry 50%-75% | Drought <50% | Total Years of Data |
|---|---|---|---|---|---|---|
| July 16 - Sept 15 | 3.61 | 21 | 22 | 15 | 12 | 70 |
| Aug 1 - Sept 30 | 4.80 | 17 | 29 | 15 | 11 | 72 |
| Aug 16 - Oct 15 | 6.17 | 21 | 24 | 16 | 7 | 68 |
| Sept 1 - Oct 31 | 8.25 | 18 | 36 | 9 | 7 | 70 |
| Sept 16 - Nov 15 | 10.69 | 12 | 42 | 10 | 5 | 69 |
| Oct 1 - Nov 30 | 13.24 | 17 | 37 | 10 | 5 | 69 |

Note: Years of data are slightly different due to missing data from the WA Climate Data Center as noted above. To see months with missing data, reference Table A or C.

The probability of occurrence of a normal antecedent precipitation period at Landsburg was calculated by dividing the number of occurrences of wet, normal, dry and drought years by the number of years of data for each antecedent precipitation period (Table E).

**Table E – Wet, Normal, Dry and Drought Probability**

| Antecedent Precipitation Period | >125% Wet Freq/Total =% | 75%-125% Normal Freq/Total =% | 50%-75% Dry Freq/Total =% | <50% Drought Freq/Total =% |
|---|---|---|---|---|
| July 16 - Sept 15 | 21/70 - 30.0% | 22/70 - 31.4% | 15/70 - 21.4% | 12/70 - 17.1% |
| Aug 1 - Sept 30 | 17/72 - 23.6% | 29/72 - 40.3% | 15/72 - 20.8% | 11/72 - 15.3% |
| Aug 16 - Oct 15 | 21/68 - 30.9% | 24/68 - 35.3% | 16/68 - 23.5% | 7/68 - 10.2% |
| Sept 1 - Oct 31 | 18/70 - 25.7% | 36/70 - 51.4% | 9/70 - 12.9% | 7/70 - 10.0% |
| Sept 16 - Nov 15 | 12/69 - 17.4% | 42/69 - 60.9% | 10/69 - 14.5% | 5/69 - 7.3% |
| Oct 1 - Nov 30 | 17/69 - 24.6% | 37/69 - 53.6% | 10/69 - 14.5% | 5/69 - 7.3% |
| **Total** | **106/418-25.7%** | **190/418-45.5%** | **75/418-17.9%** | **47/418-11.2%** |

Note: Years of data reflected in Table E are slightly different due to missing data from the WA Climate Data Center and the Western Regional Climate Data Center as noted above.

This comparison showed that since 1931, approximately 1 in 4 (25.7%) of the antecedent periods (total row in Table E) of the combined two month antecedent precipitation periods from mid-July through November would be classified as wet, approximately 1 in 2 (45.5%) antecedent precipitation periods would be classified as normal, slightly more than 1 in 6 (17.9%) periods of the antecedent precipitation as dry, and 1 in 9 (11.2%) of the combined two month antecedent precipitation periods considered a drought.

## V. Stream Flow Augmentation Goals

The City of Kent is proposing to augment Rock Creek flows during the months of October, November, and December with maximum augmentation commitments and minimum stream flow targets. The maximum flow augmentation will be based on two-month antecedent precipitation as measured at Landsburg, with a specific minimum stream flow target. The City will commit to augmenting the stream up to the minimum stream flow target, but not more than a maximum augmentation amount. At the City's

discretion, the City may provide augmentation even though the stream flow may be above the stream flow targets shown in Table F (below).

When the type of antecedent precipitation period is determined, maximum flow augmentation and the minimum stream flow target will be determined from Table F. The mean precipitation data will be re-calculated on a five year basis adding in the most recent years' data. This will require updates to Tables A through E.

**Table F – Minimum Stream Flow Targets and Maximum Augmentation**

| Antecedent Precipitation Period | Stream Flow Target | Maximum Augmentation Commitment |
|---|---|---|
| Wet Periods | 3.5 cfs | 2.5 cfs |
| Normal Periods | 3.0 cfs | 2.0 cfs |
| Dry Periods | 2.75 cfs | 1.75 cfs |
| Drought Periods | 2.5 cfs | 1.5 cfs |

Note: Minimum stream flow target to be measured at USGS Gauge No. 12118400 on the Clark Springs property. The augmentation commitment flow rate shall be measured at the flow meter on the augmentation pipe from the City's clear well.

## VI. Precipitation Data Collection for the HCP

Precipitation data is currently being collected at Clark Springs and is available in real time (15-minute increments) concurrent with USGS Gauge No. 12118400 located on the Clark Springs property. Because this precipitation has only been collected since 2003, determination of wet/normal/dry/drought years will be determined by the antecedent precipitation period as measured at Landsburg. During the HCP implementation period, the City of Kent will compare data collected at Landsburg with the real time data collected at Clark Springs. With additional data collection, the City may, in the future, as a part of the adaptive management and monitoring element of the HCP, alter the location of the precipitation monitoring point with concurrence from the Services.

The City is also attempting to secure access to a monitoring well located approximately ½ mile east of Clark Springs which was installed as a part of the hydrogeologic study for the recent McCann boundary line adjustment. Access to this well would provide the City of Kent a water table measurement from a non-production well in the upper basin south of Kent Kangley Road and west of 268$^{th}$ Avenue SE. Being able to collect water table data from a monitoring well would provide a means for the City to measure available groundwater and determine mean groundwater levels over time. This data, combined with precipitation data in the watershed, could be used as a tool in the future as a part of adaptive management.

Ten years after the implementation of the Incidental Take Permit and the HCP, the City of Kent proposes to meet with the services to re-evaluate the location for the collection of the precipitation information and the aquifer level collection data within the watershed. For the first ten years of the HCP, the source for precipitation data will be the gauge at

Landsburg. However, in the future, after the City has evaluated the additional data available from the USGS precipitation gauge at the Clark Springs facility, the City may propose to change the location for the collection of precipitation information to be the Clark Springs site. The City may also propose changes to methodology of determining wet/normal/dry/drought antecedent precipitation periods based on additional aquifer level and/or precipitation data.

*This page intentionally left blank.*

# LANDSBURG, WASHINGTON

## Monthly Total Precipitation (inches)

## Table A

**454486**

File last updated on Mar 31, 2005
*** Note *** Provisional Data *** After Year/Month 200412
a = 1 day missing, b = 2 days missing, c = 3 days, ..etc..,
z = 26 or more days missing, A = Accumulations present
Long-term means based on columns; thus, the monthly row may not
sum (or average) to the long-term annual value.
MAXIMUM ALLOWABLE NUMBER OF MISSING DAYS : 5
Individual Months not used for statistics if more than 5 days are missing.

| | **July** | | | | **August** | | | | **September** | | | | **October** | | | | **November** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YEAR(S) | 1-15 | 16-31 | Total | | 1-15 | 16-31 | Total | | 1-15 | 16-30 | Total | | 1-15 | 16-31 | Total | | 1-15 | 16-30 | Total | |
| 1931 | 0.08 | 0.00 | 0.08 | | 0.08 | 0.30 | 0.38 | | 3.82 | 1.58 | 5.40 | | 1.29 | 5.03 | 6.32 | | 2.83 | 1.50 | 4.33 | |
| 1932 | 2.84 | 0.15 | 2.99 | | 0.49 | 1.56 | 2.05 | e | 0.12 | 0.91 | 1.03 | | 1.96 | 4.46 | 6.42 | | 9.79 | 2.69 | 12.48 | |
| 1933 | 0.45 | 0.70 | 1.15 | | 2.17 | 0.61 | 2.78 | | 2.88 | 4.61 | 7.49 | | 0.00 | 6.47 | 6.47 | | 3.93 | 2.17 | 6.10 | |
| 1934 | 0.13 | 0.89 | 1.02 | | 0.66 | 0.00 | 0.66 | | 3.24 | 1.27 | 4.51 | | 2.01 | 8.39 | 10.40 | | 7.73 | 2.45 | 10.18 | |
| 1935 | na | na | na | z | 0.10 | 0.86 | 0.96 | | 2.56 | 0.45 | 3.01 | | 1.80 | 3.82 | 5.62 | a | 1.44 | 1.53 | 2.97 | |
| 1936 | 2.06 | 0.00 | 2.06 | | 0.00 | 0.30 | 0.30 | a | 4.23 | 0.30 | 4.53 | c | na | na | na | f | 0.56 | 1.08 | 1.64 | |
| 1937 | 0.53 | 0.15 | 0.68 | | na | na | na | z | 1.01 | 0.95 | 1.96 | | 0.54 | 3.45 | 3.99 | | 8.82 | 5.64 | 14.46 | a |
| 1938 | 0.45 | 0.00 | 0.45 | | 1.20 | 0.00 | 1.20 | | 1.15 | 0.49 | 1.64 | | 2.49 | 2.03 | 4.52 | a | 2.95 | 2.19 | 5.14 | |
| 1939 | 2.05 | 0.25 | 2.30 | | 0.04 | 1.06 | 1.10 | | 2.55 | 0.12 | 2.67 | a | 1.92 | 1.72 | 3.64 | | 3.32 | 1.76 | 5.08 | |
| 1940 | 0.03 | 2.54 | 2.57 | | 0.45 | 0.70 | 1.15 | | 1.37 | 1.73 | 3.10 | | 2.76 | 4.77 | 7.53 | | 2.20 | 3.20 | 5.40 | |
| 1941 | 0.00 | 0.18 | 0.18 | | 0.72 | 2.04 | 2.76 | | 3.47 | 1.45 | 4.92 | | 2.88 | 1.08 | 3.96 | | 4.06 | 1.10 | 5.16 | |
| 1942 | 0.53 | 1.20 | 1.73 | | 0.02 | 1.13 | 1.15 | | 0.42 | 0.37 | 0.79 | a | 0.78 | 3.88 | 4.66 | | 4.59 | 5.19 | 9.78 | |
| 1943 | 0.63 | 0.00 | 0.63 | | 0.65 | 0.67 | 1.32 | | 0.53 | 0.36 | 0.89 | | 3.05 | 4.57 | 7.62 | | 0.98 | 1.66 | 2.64 | |
| 1944 | 0.32 | 0.12 | 0.44 | | 0.75 | 0.37 | 1.12 | | 1.53 | 2.48 | 4.01 | | 1.19 | 1.84 | 3.03 | | 3.17 | 3.43 | 6.60 | |
| 1945 | 0.00 | 0.26 | 0.26 | | 0.07 | 0.89 | 0.96 | | 4.10 | 4.23 | 8.33 | | na | na | na | i | 4.43 | 4.69 | 9.12 | |
| 1946 | 1.77 | 0.04 | 1.81 | | 0.15 | 0.20 | 0.35 | | 1.33 | 1.32 | 2.65 | | 1.12 | 4.39 | 5.51 | | 0.88 | 6.54 | 7.42 | a |
| 1947 | 0.93 | 0.65 | 1.58 | | 0.11 | 0.98 | 1.09 | | 1.81 | 2.44 | 4.25 | | 4.08 | 7.30 | 11.38 | | 5.18 | 2.87 | 8.05 | |
| 1948 | 2.06 | 1.18 | 3.24 | | 0.99 | 1.79 | 2.78 | | 0.96 | 3.79 | 4.75 | | 2.02 | 1.35 | 3.37 | | 2.94 | 6.51 | 9.45 | |
| 1949 | 0.00 | 1.59 | 1.59 | | 0.39 | 0.69 | 1.08 | | 1.30 | 1.04 | 2.34 | | 3.66 | 1.78 | 5.44 | | 3.50 | 4.73 | 8.23 | |
| 1950 | 0.44 | 0.90 | 1.34 | | 2.23 | 0.72 | 2.95 | | 0.24 | 2.98 | 3.22 | | 4.53 | 4.68 | 9.21 | | 1.98 | 7.05 | 9.03 | |
| 1951 | 0.06 | 0.00 | 0.06 | | 0.31 | 1.80 | 2.11 | | 0.55 | 2.81 | 3.36 | | 3.52 | 3.67 | 7.19 | | 4.51 | 2.53 | 7.04 | |
| 1952 | 0.00 | 1.24 | 1.24 | | 0.08 | 0.78 | 0.86 | | 0.58 | 0.00 | 0.58 | | 0.00 | 1.54 | 1.54 | | 1.38 | 0.02 | 1.40 | |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1953 | 1.34 | 0.09 | 1.43 | | 0.31 | 2.18 | 2.49 | | 0.19 | 2.67 | 2.86 | | 3.31 | 3.18 | 6.49 | | 3.33 | 5.21 | 8.54 | |
| 1954 | 2.21 | 0.39 | 2.60 | | 0.52 | 2.39 | 2.91 | | 1.93 | 2.01 | 3.94 | | 0.93 | 1.45 | 2.38 | | 2.74 | 4.10 | 6.84 | |
| 1955 | 1.10 | 2.33 | 3.43 | | 0.64 | 0.08 | 0.72 | | 1.36 | 1.31 | 2.67 | | 4.96 | 4.51 | 9.47 | | 1.99 | 5.76 | 7.75 | |
| 1956 | 0.51 | 0.00 | 0.51 | | 0.36 | 0.68 | 1.04 | | 1.00 | 2.15 | 3.15 | | 2.10 | 7.00 | 9.10 | | 1.59 | 1.44 | 3.03 | |
| 1957 | 1.00 | 0.20 | 1.20 | | 1.89 | 0.02 | 1.91 | | 0.41 | 0.87 | 1.28 | | 2.52 | 2.96 | 5.48 | | 3.79 | 1.49 | 5.28 | |
| 1958 | 0.00 | 0.00 | 0.00 | | 0.34 | 0.99 | 1.33 | | 0.43 | 1.44 | 1.87 | | 2.34 | 2.60 | 4.94 | | 6.18 | 5.22 | 11.40 | |
| 1959 | 1.26 | 0.10 | 1.36 | | 0.01 | 1.28 | 1.29 | | 3.37 | 5.14 | 8.51 | | 2.06 | 2.56 | 4.62 | | 2.01 | 8.74 | 10.75 | |
| 1960 | 0.00 | 0.00 | 0.00 | | 0.47 | 2.87 | 3.34 | | 1.26 | 0.65 | 1.91 | | 1.84 | 5.41 | 7.25 | | 4.56 | 7.19 | 11.75 | |
| 1961 | 1.21 | 0.00 | 1.21 | | 0.13 | 1.50 | 1.63 | | 0.60 | 1.14 | 1.74 | | 2.37 | 2.14 | 4.51 | | 2.04 | 2.71 | 4.75 | |
| 1962 | 1.19 | 0.10 | 1.29 | | 2.42 | 0.87 | 3.29 | | 1.82 | 1.62 | 3.44 | | 4.32 | 0.43 | 4.75 | | 3.99 | 7.54 | 11.53 | |
| 1963 | 2.21 | 1.17 | 3.38 | | 0.05 | 0.98 | 1.03 | | 1.30 | 0.49 | 1.79 | | 1.11 | 5.13 | 6.24 | | 5.76 | 4.46 | 10.22 | |
| 1964 | 1.52 | 1.18 | 2.70 | | 1.20 | 1.93 | 3.13 | | 1.63 | 3.91 | 5.54 | | 2.18 | 0.81 | 2.99 | | 4.23 | 6.45 | 10.68 | |
| 1965 | 0.30 | 0.47 | 0.77 | | 1.51 | 1.80 | 3.31 | | 1.07 | 0.07 | 1.14 | | 2.80 | 1.58 | 4.38 | | 3.62 | 2.45 | 6.07 | |
| 1966 | 2.17 | 0.18 | 2.35 | | 0.43 | 0.62 | 1.05 | | 0.55 | 1.61 | 2.16 | | 1.35 | 3.74 | 5.09 | | 3.40 | 4.26 | 7.66 | |
| 1967 | 0.03 | 0.10 | 0.13 | | 0.01 | 0.02 | 0.03 | | 2.21 | 0.56 | 2.77 | | 3.65 | 4.21 | 7.86 | | 2.58 | 1.06 | 3.64 | |
| 1968 | 0.59 | 0.20 | 0.79 | | 2.40 | 4.21 | 6.61 | | 1.15 | 2.23 | 3.38 | | 3.69 | 1.96 | 5.65 | | 4.52 | 3.42 | 7.94 | |
| 1969 | 0.66 | 0.00 | 0.66 | | 0.15 | 0.31 | 0.46 | | 0.49 | 6.74 | 7.23 | | 1.45 | 0.83 | 2.28 | | 2.67 | 1.31 | 3.98 | |
| 1970 | 0.00 | 2.03 | 2.03 | | 0.42 | 0.01 | 0.43 | | 1.71 | 2.37 | 4.08 | | 1.80 | 2.63 | 4.43 | | 3.23 | 3.77 | 7.00 | |
| 1971 | 1.84 | 0.00 | 1.84 | | 0.00 | 1.05 | 1.05 | | 4.21 | 2.03 | 6.24 | | 1.23 | 3.47 | 4.70 | | 4.50 | 2.41 | 6.91 | |
| 1972 | 3.14 | 0.03 | 3.17 | | 0.69 | 0.87 | 1.56 | | 1.54 | 4.97 | 6.51 | | 0.25 | 1.84 | 2.09 | | 2.58 | 2.47 | 5.05 | |
| 1973 | 0.22 | 0.05 | 0.27 | | 0.19 | 0.42 | 0.61 | | 0.56 | 3.02 | 3.58 | | 2.66 | 2.63 | 5.29 | | 5.31 | 4.40 | 9.71 | |
| 1974 | na | na | na | z | 0.00 | 0.73 | 0.73 | | 0.44 | 0.04 | 0.48 | | 0.17 | 1.84 | 2.01 | | 2.74 | 6.87 | 9.61 | |
| 1975 | 0.30 | 0.54 | 0.84 | | 0.47 | 4.58 | 5.05 | | 0.03 | 0.09 | 0.12 | | 3.64 | 7.55 | 11.19 | | 4.73 | 3.80 | 8.53 | |
| 1976 | 2.33 | 0.00 | 2.33 | | 2.73 | 2.09 | 4.82 | | 0.95 | 0.13 | 1.08 | | 0.20 | 2.65 | 2.85 | | 0.71 | 1.27 | 1.98 | |
| 1977 | 0.51 | 0.01 | 0.52 | | 0.00 | 4.00 | 4.00 | | 0.40 | 3.64 | 4.04 | | 0.30 | 3.09 | 3.39 | | 4.14 | 3.43 | 7.57 | |
| 1978 | 0.38 | 1.43 | 1.81 | | 0.89 | 1.46 | 2.35 | | 4.02 | 3.46 | 7.48 | | 0.15 | 0.91 | 1.06 | | 3.44 | 4.99 | 8.43 | |
| 1979 | 2.37 | 0.00 | 2.37 | | 0.22 | 0.75 | 0.97 | | 2.91 | 0.40 | 3.31 | | 0.31 | 4.36 | 4.67 | | 0.30 | 1.20 | 1.50 | |
| 1980 | 0.71 | 0.12 | 0.83 | | 0.04 | 1.54 | 1.58 | | 1.77 | 1.02 | 2.79 | | 1.21 | 1.10 | 2.31 | | 7.98 | 9.81 | 17.79 | |
| 1981 | 1.94 | 0.04 | 1.98 | | 0.00 | 0.44 | 0.44 | | 0.58 | 3.50 | 4.08 | | 5.13 | 1.93 | 7.06 | | 1.86 | 3.06 | 4.92 | |
| 1982 | 1.62 | 0.29 | 1.91 | | 1.42 | 0.37 | 1.79 | | 2.54 | 1.32 | 3.86 | | 1.23 | 4.06 | 5.29 | | 1.60 | 4.60 | 6.20 | |
| 1983 | 2.94 | 0.99 | 3.93 | | 1.15 | 1.43 | 2.58 | | 2.94 | 1.34 | 4.28 | | 0.20 | 2.92 | 3.12 | | 6.59 | 4.04 | 10.63 | |
| 1984 | 0.04 | 0.00 | 0.04 | | 0.00 | 0.30 | 0.30 | | 0.72 | 0.66 | 1.38 | | na | na | na | z | na | na | na | z |
| 1985 | 0.00 | 0.20 | 0.20 | | 1.72 | 0.21 | 1.93 | | 1.95 | 0.80 | 2.75 | | 0.78 | 8.26 | 9.04 | | 4.83 | 2.68 | 7.51 | |
| 1986 | 1.50 | 0.75 | 2.25 | | 0.00 | 0.51 | 0.51 | | 0.73 | 3.21 | 3.94 | | 0.00 | 4.39 | 4.39 | | 1.96 | 10.37 | 12.33 | |
| 1987 | 0.25 | 0.10 | 0.35 | | 0.48 | 0.00 | 0.48 | | 0.72 | 0.53 | 1.25 | | 0.09 | 0.30 | 0.39 | | 1.90 | 1.38 | 3.28 | |
| 1988 | 1.48 | 0.00 | 1.48 | | 0.10 | 0.49 | 0.59 | | 0.19 | 3.05 | 3.24 | | 1.40 | 2.81 | 4.21 | | 5.98 | 4.65 | 10.63 | |
| 1989 | 0.25 | 0.83 | 1.08 | | 0.33 | 0.79 | 1.12 | | 0.36 | 0.49 | 0.85 | | 1.11 | 2.04 | 3.15 | | 5.35 | 1.99 | 7.34 | |
| 1990 | 1.26 | 0.22 | 1.48 | | 0.00 | 2.95 | 2.95 | | 0.23 | 0.05 | 0.28 | | 3.44 | 6.27 | 9.71 | | 7.83 | 6.83 | 14.66 | |
| 1991 | 0.08 | 0.46 | 0.54 | | 0.17 | 1.68 | 1.85 | | 0.10 | 0.00 | 0.10 | | 0.00 | 2.10 | 2.10 | | 4.13 | 5.55 | 9.68 | |
| 1992 | 2.57 | 0.59 | 3.16 | | 0.85 | 0.01 | 0.86 | a | 0.45 | 1.90 | 2.35 | | 0.96 | 2.28 | 3.24 | | 4.28 | 4.06 | 8.34 | |
| 1993 | 0.63 | 2.24 | 2.87 | | 0.00 | 0.94 | 0.94 | | 0.03 | 0.01 | 0.04 | | 2.38 | 1.93 | 4.31 | | 0.20 | 2.60 | 2.80 | |

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1994 | 0.75 | 0.28 | 1.03 | | 0.35 | 0.18 | 0.53 | | 3.00 | 0.00 | 3.00 | | 0.75 | 5.17 | 5.92 | | 2.67 | 5.67 | 8.34 | | | | | |
| 1995 | 0.82 | 0.53 | 1.35 | | 1.04 | 1.70 | 2.74 | | 0.34 | 1.44 | 1.78 | | 4.74 | 1.73 | 6.47 | | 5.83 | 7.68 | 13.51 | | | | | |
| 1996 | 0.49 | 0.77 | 1.26 | | 0.85 | 0.20 | 1.05 | | 1.83 | 1.39 | 3.22 | | 2.96 | 5.62 | 8.58 | | 3.28 | 6.60 | 9.88 | | | | | |
| 1997 | 3.76 | 0.00 | 3.76 | | 0.00 | 1.36 | 1.36 | | 0.77 | 2.87 | 3.64 | | 3.90 | 3.83 | 7.73 | | 1.21 | 3.67 | 4.88 | | | | | |
| 1998 | 0.73 | 0.06 | 0.79 | a | na | na | na | z | 0.00 | 1.41 | 1.41 | | 2.58 | 1.30 | 3.88 | | 3.92 | 9.43 | 13.35 | | | | | |
| 1999 | 1.48 | 1.30 | 2.78 | | 1.52 | 0.26 | 1.78 | | 0.06 | 0.45 | 0.51 | | 2.82 | 1.75 | 4.57 | | 7.17 | 6.12 | 13.29 | | | | | |
| 2000 | 0.84 | 0.05 | 0.89 | | 0.00 | 0.62 | 0.62 | | 1.96 | 1.48 | 3.44 | | na | na | na | z | 2.25 | 1.87 | 4.12 | | | | | |
| 2001 | na | na | na | z | 0.03 | 3.04 | 3.07 | | 0.62 | 1.15 | 1.77 | | 1.96 | 3.48 | 5.44 | a | 6.52 | 6.42 | 12.94 | | | | | |
| 2002 | 1.21 | 0.28 | 1.49 | | 0.10 | 0.62 | 0.72 | | 0.53 | 0.00 | 0.53 | c | 1.35 | 0.36 | 1.71 | | na | na | na | z | | | | |
| 2003 | 0.21 | 0.00 | 0.21 | | 0.28 | 0.03 | 0.31 | a | 1.26 | 1.19 | 2.45 | | 1.73 | 8.76 | 10.49 | a | 0.70 | 6.55 | 7.25 | | | | | |
| 2004 | 1.07 | 0.02 | 1.09 | | 0.93 | 6.85 | 7.78 | | 2.97 | 1.54 | 4.51 | | 1.65 | 2.50 | 4.15 | | 2.02 | 4.42 | 6.44 | | | | | |

Period of Record Monthly Statistics

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MEAN | 0.99 | 0.46 | 1.45 | 0.58 | 1.15 | 1.72 | 1.40 | 1.64 | 3.04 | 1.97 | 3.32 | 5.29 | 3.64 | 4.14 | 7.78 | |
| MAX | 3.76 | 2.54 | 3.93 | 2.73 | 6.85 | 7.78 | 4.23 | 6.74 | 8.51 | 5.13 | 8.76 | 11.38 | 9.79 | 10.37 | 17.79 | |
| Year | 1997 | 1940 | 1983 | 1976 | 2004 | 2004 | 1936 | 1969 | 1959 | 1981 | 2003 | 1947 | 1932 | 1986 | 1980 | |
| MIN | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.04 | 0.00 | 0.30 | 0.39 | 0.20 | 0.02 | 1.40 | |
| Year or frq | 8x | 17x | 2x | 10x | 3x | 1967 | 1998 | 4x | 1993 | 4x | 1936 | 1987 | 1993 | 1952 | 1952 | |
| NO YRS | 71 | 71 | 71 | 72 | 72 | 72 | 74 | 74 | 74 | 70 | 70 | 70 | 72 | 72 | 72 | |

* indicates missing data see comments above
The data above was derived from the Western Regional Climate Center web site data.
Original data is available at the web address below under Period of Record - Precipitation -
Monthly Precipitation Listings - Monthly Totals http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?waland

| December | | | Annual | Bi-Monthly Periods | | | | | | | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-15 | 16-31 | Total | Total | 7/16-9/15 | 8/1-9/30 | 8/16-10/15 | 9/1-10/31 | 9/16-11/15 | 10/1-11/30 | 10/16-12/15 | Total |
| 2.26 | 5.75 | 8.01 | 58.14 | 4.20 | 5.78 | 6.99 | 11.72 | 10.73 | 10.65 | 11.62 | 58.14 |
| 1.30 | 5.14 | 6.44 | 63.68 | 2.32 | 3.08 | 4.55 | 7.45 | 17.12 | 18.90 | 18.24 | 63.68 |
| 11.06 | 11.57 | 22.63 | 75.98 | 6.36 | 10.27 | 8.10 | 13.96 | 15.01 | 12.57 | 23.63 | 75.98 |
| 1.82 | 5.02 | 6.84 | 61.68 | 4.79 | 5.17 | 6.52 | 14.91 | 19.40 | 20.58 | 20.39 | 61.68 |
| 2.31 | 2.90 | 5.21 | * | na * | 3.97 | 5.67 | 8.63 | 7.51 | 8.59 | 9.10 | * |
| 6.60 | 5.89 | 12.49 | * | 4.53 | 4.83 | na * | na * | na * | na * | na * | * |
| 1.95 | 6.62 | 8.57 | * | 1.16 | na * | na * | 5.95 | 13.76 | 18.45 | 19.86 | * |
| 2.78 | 3.03 | 5.81 | 42.01 | 2.35 | 2.84 | 4.13 | 6.16 | 7.96 | 9.66 | 9.95 | 42.01 |
| 5.31 | 3.38 | 8.69 | 51.59 | 3.90 | 3.77 | 5.65 | 6.31 | 7.08 | 8.72 | 12.11 | 51.59 |
| 2.36 | 3.40 | 5.76 | 52.83 | 5.06 | 4.25 | 6.56 | 10.63 | 11.46 | 12.93 | 12.53 | 52.83 |
| 3.45 | 6.37 | 9.82 | 47.10 | 6.41 | 7.68 | 9.84 | 8.88 | 9.47 | 9.12 | 9.69 | 47.10 |
| 3.26 | 2.96 | 6.22 | 46.98 | 2.77 | 1.94 | 2.70 | 5.45 | 9.62 | 14.44 | 16.92 | 46.98 |
| 2.22 | 1.78 | 4.00 | 40.13 | 1.85 | 2.21 | 4.61 | 8.51 | 8.96 | 10.26 | 9.43 | 40.13 |
| 2.33 | 0.99 | 3.32 | 41.35 | 2.77 | 5.13 | 5.57 | 7.04 | 8.68 | 9.63 | 10.77 | 41.35 |
| 1.91 | 4.69 | 6.60 | * | 5.32 | 9.29 | na * | na * | na * | na * | na * | * |
| 9.37 | 0.42 | 9.79 | * | 1.72 | 3.00 | 3.97 | 8.16 | 7.71 | 12.93 | 21.18 | * |
| 2.17 | 5.12 | 7.29 | 62.77 | 3.55 | 5.34 | 9.31 | 15.63 | 19.00 | 19.43 | 17.52 | 62.77 |
| 5.98 | 2.95 | 8.93 | 68.42 | 4.92 | 7.53 | 8.56 | 8.12 | 10.10 | 12.82 | 16.78 | 68.42 |
| 2.20 | 6.96 | 9.16 | 49.70 | 3.97 | 3.42 | 6.69 | 7.78 | 9.98 | 13.67 | 12.21 | 49.70 |
| 3.91 | 5.89 | 9.80 | 72.54 | 4.09 | 6.17 | 8.47 | 12.43 | 14.17 | 18.24 | 17.62 | 72.54 |
| 2.48 | 3.66 | 6.14 | 56.03 | 2.66 | 5.47 | 8.68 | 10.55 | 14.51 | 14.23 | 13.19 | 56.03 |
| 3.43 | 1.87 | 5.30 | 32.93 | 2.68 | 1.44 | 1.36 | 2.12 | 2.92 | 2.94 | 6.37 | 32.93 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6.43 | 3.63 | 10.06 | | 71.73 | | 2.77 | | 5.35 | | 8.35 | | 9.35 | | 12.49 | | 15.03 | | 18.15 | | 71.73 |
| 2.39 | 4.56 | 6.95 | | 53.00 | | 5.23 | | 6.85 | | 7.26 | | 6.32 | | 7.13 | | 9.22 | | 10.68 | | 53.00 |
| 5.69 | 4.99 | 10.68 | | 63.07 | | 4.41 | | 3.39 | | 7.71 | | 12.14 | | 12.77 | | 17.22 | | 17.95 | | 63.07 |
| 6.17 | 1.78 | 7.95 | | 52.39 | | 2.04 | | 4.19 | | 5.93 | | 12.25 | | 12.84 | | 12.13 | | 16.20 | | 52.39 |
| 2.04 | 5.91 | 7.95 | | 50.38 | | 2.52 | | 3.19 | | 3.82 | | 6.76 | | 10.14 | | 10.76 | | 10.28 | | 50.38 |
| 5.48 | 5.07 | 10.55 | | 57.71 | | 1.76 | | 3.20 | | 5.20 | | 6.81 | | 12.56 | | 16.34 | | 19.48 | | 57.71 |
| 6.48 | 1.78 | 8.26 | | 66.72 | | 4.76 | | 9.80 | | 11.85 | | 13.13 | | 11.77 | | 15.37 | | 19.79 | | 66.72 |
| 2.28 | 2.38 | 4.66 | | 57.99 | | 4.60 | | 5.25 | | 6.62 | | 9.16 | | 12.46 | | 19.00 | | 19.44 | | 57.99 |
| 1.93 | 5.96 | 7.89 | | 59.29 | | 2.23 | | 3.37 | | 5.61 | | 6.25 | | 7.69 | | 9.26 | | 8.82 | | 59.29 |
| 3.29 | 4.16 | 7.45 | | 54.89 | | 5.21 | | 6.73 | | 8.63 | | 8.19 | | 10.36 | | 16.28 | | 15.25 | | 54.89 |
| 2.87 | 3.84 | 6.71 | | 55.83 | | 3.50 | | 2.82 | | 3.88 | | 8.03 | | 12.49 | | 16.46 | | 18.22 | | 55.83 |
| 2.58 | 5.33 | 7.91 | | 70.26 | | 5.94 | | 8.67 | | 9.65 | | 8.53 | | 11.13 | | 13.67 | | 14.07 | | 70.26 |
| 2.96 | 3.68 | 6.64 | | 48.09 | | 4.85 | | 4.45 | | 5.74 | | 5.52 | | 8.07 | | 10.45 | | 10.61 | | 48.09 |
| 5.34 | 4.54 | 9.88 | | 54.89 | | 1.78 | | 3.21 | | 4.13 | | 7.25 | | 10.10 | | 12.75 | | 16.74 | | 54.89 |
| 2.65 | 4.38 | 7.03 | | 51.40 | | 2.34 | | 2.80 | | 6.44 | | 10.63 | | 11.00 | | 11.50 | | 10.50 | | 51.40 |
| 5.69 | 3.13 | 8.82 | | 66.26 | | 7.96 | | 9.99 | | 11.28 | | 9.03 | | 12.40 | | 13.59 | | 15.59 | | 66.26 |
| 5.07 | 4.09 | 9.16 | | 52.91 | | 0.95 | | 7.69 | | 8.99 | | 9.51 | | 11.69 | | 6.26 | | 9.88 | | 52.91 |
| 5.81 | 3.75 | 9.56 | | 55.94 | | 4.17 | | 4.51 | | 5.89 | | 8.51 | | 10.03 | | 11.43 | | 15.44 | | 55.94 |
| 4.60 | 4.12 | 8.72 | | 64.36 | | 5.26 | | 7.29 | | 8.52 | | 10.94 | | 11.23 | | 11.61 | | 14.98 | | 64.36 |
| 2.33 | 8.74 | 11.07 | | 71.13 | | 3.13 | | 8.07 | | 7.63 | | 8.60 | | 9.64 | | 7.14 | | 9.22 | | 71.13 |
| 5.71 | 5.05 | 10.76 | | 53.00 | | 1.22 | | 4.19 | | 6.66 | | 8.87 | | 13.62 | | 15.00 | | 18.05 | | 52.99 |
| 3.76 | 5.49 | 9.25 | | * | | na | * | 1.21 | | 1.38 | | 2.49 | | 4.79 | | 11.62 | | 15.21 | | * |
| 7.01 | 4.74 | 11.75 | | 76.39 | | 5.62 | | 5.17 | | 8.34 | | 11.31 | | 16.01 | | 19.72 | | 23.09 | | 76.39 |
| 1.73 | 3.52 | 5.25 | | 43.73 | | 5.77 | | 5.90 | | 3.37 | | 3.93 | | 3.69 | | 4.83 | | 6.36 | | 43.73 |
| 8.89 | 0.89 | 9.78 | | 50.19 | | 4.41 | | 8.04 | | 8.34 | | 7.43 | | 11.17 | | 10.96 | | 19.55 | | 50.19 |
| 2.67 | 1.25 | 3.92 | | 47.57 | | 7.80 | | 9.83 | | 9.09 | | 8.54 | | 7.96 | | 9.49 | | 12.01 | | 47.57 |
| 10.29 | 5.71 | 16.00 | | 54.16 | | 3.88 | | 4.28 | | 4.37 | | 7.98 | | 5.37 | | 6.17 | | 16.15 | | 54.16 |
| 6.14 | 6.26 | 12.40 | | 68.87 | | 3.47 | | 4.37 | | 5.54 | | 5.10 | | 11.31 | | 20.10 | | 25.03 | | 68.87 |
| 5.61 | 3.07 | 8.68 | | * | | 1.06 | | 4.52 | | 9.65 | | 11.14 | | 12.42 | | 11.98 | | 12.46 | | * |
| 5.23 | 2.42 | 7.65 | | 58.57 | | 4.62 | | 5.65 | | 5.46 | | 9.15 | | 8.21 | | 11.49 | | 15.49 | | 58.57 |
| 3.95 | 2.10 | 6.05 | b | 59.20 | | 6.51 | | 6.86 | | 5.91 | | 7.40 | | 11.05 | | 13.75 | | 17.50 | | 59.20 |
| 3.57 | 2.88 | 6.45 | | * | | 1.02 | | 1.68 | | na | * | na | * | na | * | na | * | na | * | * |
| 1.75 | 0.28 | 2.03 | | * | | 4.08 | | 4.68 | | 3.74 | | 11.79 | | 14.67 | | 16.55 | | 17.52 | | * |
| 1.13 | 3.02 | 4.15 | | 54.79 | | 1.99 | | 4.45 | | 4.45 | | 8.33 | | 9.56 | | 16.72 | | 17.85 | | 54.79 |
| 7.45 | 0.81 | 8.26 | | 39.60 | | 1.30 | | 1.73 | | 1.34 | | 1.64 | | 2.82 | | 3.67 | | 11.03 | | 39.60 |
| 1.90 | 3.51 | 5.41 | | 53.73 | | 0.78 | | 3.83 | | 5.13 | | 7.45 | | 13.24 | | 14.84 | | 15.34 | | 53.73 |
| 4.91 | 1.02 | 5.93 | | 50.24 | | 2.31 | | 1.97 | | 2.75 | | 4.00 | | 8.99 | | 10.49 | | 14.29 | | 50.24 |
| 3.40 | 1.25 | 4.65 | | 71.03 | | 3.40 | | 3.23 | | 6.67 | | 9.99 | | 17.59 | | 24.37 | | 24.33 | | 71.03 |
| 3.38 | 1.21 | 4.59 | | 54.32 | | 2.41 | | 1.95 | | 1.78 | | 2.20 | | 6.23 | | 11.78 | | 15.16 | | 54.32 |
| 3.43 | 3.04 | 6.47 | | 47.91 | | 1.90 | | 3.21 | | 3.32 | | 5.59 | | 9.42 | | 11.58 | | 14.05 | | 47.91 |
| 4.74 | 1.34 | 6.08 | | 45.00 | | 3.21 | | 0.98 | | 3.36 | | 4.35 | | 4.52 | | 7.11 | | 9.47 | | 45.00 |

| | | | | |
|---|---|---|---|---|
| 1.97 | 5.28 | 7.25 | | 52.91 |
| 4.48 | 2.09 | 6.57 | | 56.76 |
| 4.57 | 7.80 | 12.37 | | 72.48 |
| 0.99 | 4.21 | 5.20 | | * |
| 5.37 | 6.03 | 11.40 | | * |
| 5.59 | 1.55 | 7.14 | | 63.28 |
| 0.74 | 2.92 | 3.66 | | * |
| 6.24 | 2.33 | 8.57 | | * |
| 3.53 | 3.50 | 7.03 | | * |
| 4.37 | 1.05 | 5.42 | b | 58.66 |
| 5.01 | 0.92 | 5.93 | | 56.68 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3.81 | 3.53 | 3.93 | 8.92 | 8.59 | 14.26 | 15.48 | 52.91 |
| 3.61 | 4.52 | 8.22 | 8.25 | 13.74 | 19.98 | 19.72 | 56.76 |
| 3.65 | 4.27 | 6.38 | 11.80 | 13.25 | 18.46 | 20.07 | 72.48 |
| 2.13 | 5.00 | 8.90 | 11.37 | 11.81 | 12.61 | 9.70 | * |
| na * | na * | na * | 5.29 | 9.21 | 17.23 | 20.02 | * |
| 3.14 | 2.29 | 3.59 | 5.08 | 12.19 | 17.86 | 20.63 | 63.28 |
| 2.63 | 4.06 | na * | na * | na * | na * | na * | * |
| na * | 4.84 | 6.77 | 7.21 | 13.11 | 18.38 | 22.66 | * |
| 1.53 | 1.25 | 2.50 | 2.24 | na * | na * | na * | * |
| 1.57 | 2.76 | 4.21 | 12.94 | 12.38 | 17.74 | 20.38 | 58.66 |
| 10.77 | 12.29 | 13.01 | 8.66 | 7.71 | 10.59 | 13.95 | 56.68 |

**Period of Record Bi-Monthly Statistics**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 4.08 | 3.77 | 7.85 | 56.52 | 3.61 | 4.80 | 6.17 | 8.25 | 10.69 | 13.24 | 15.41 | 56.52 |
| | 11.06 | 11.57 | 22.63 | 76.39 | 10.77 | 12.29 | 13.01 | 15.63 | 19.40 | 24.37 | 25.03 | 76.39 |
| | 1933 | 1933 | 1933 | 1975 | 2004 | 2004 | 2004 | 1947 | 1934 | 1990 | 1980 | 1975 |
| | 0.74 | 0.28 | 2.03 | 32.93 | 0.78 | 0.98 | 1.34 | 1.64 | 2.82 | 2.94 | 6.36 | 32.93 |
| | 2000 | 1985 | 1985 | 1952 | 1988 | 1993 | 1987 | 1987 | 1987 | 1952 | 1976 | 1952 |
| | 74 | 74 | 74 | 60 | 70 | 72 | 68 | 70 | 69 | 69 | 69 | 60 |

**Table C**

| Year | 7/16-9/15 | 8/1-9/30 | 8/16-10/15 | 9/1-10/31 | 9/16-11/15 | 10/1-11/30 | 10/16-12/15 | ANNUAL | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 1931 | 4.20 | 5.78 | 6.99 | 11.72 | 10.73 | 10.65 | 11.62 | 58.14 | |
| 1932 | 2.32 | 3.08 | 4.55 | 7.45 | 17.12 | 18.90 | 18.24 | 63.68 | |
| 1933 | 6.36 | 10.27 | 8.10 | 13.96 | 15.01 | 12.57 | 23.63 | 75.98 | |
| 1934 | 4.79 | 5.17 | 6.52 | 14.91 | 19.40 | 20.58 | 20.39 | 61.68 | |
| 1935 | na * | 3.97 | 5.67 | 8.63 | 7.51 | 8.59 | 9.10 | * | 26+ days missing data in July |
| 1936 | 4.53 | 4.83 | na * | na * | na * | na * | na * | * | 6 days missing data in October |
| 1937 | 1.16 | na * | na * | 5.95 | 13.76 | 18.45 | 19.86 | * | 26+ days missing data in August |
| 1938 | 2.35 | 2.84 | 4.13 | 6.16 | 7.96 | 9.66 | 9.95 | 42.01 | |
| 1939 | 3.90 | 3.77 | 5.65 | 6.31 | 7.08 | 8.72 | 12.11 | 51.59 | |
| 1940 | 5.06 | 4.25 | 6.56 | 10.63 | 11.46 | 12.93 | 12.53 | 52.83 | |
| 1941 | 6.41 | 7.68 | 9.84 | 8.88 | 9.47 | 9.12 | 9.69 | 47.10 | |
| 1942 | 2.77 | 1.94 | 2.70 | 5.45 | 9.62 | 14.44 | 16.92 | 46.98 | |
| 1943 | 1.85 | 2.21 | 4.61 | 8.51 | 8.96 | 10.26 | 9.43 | 40.13 | |
| 1944 | 2.77 | 5.13 | 5.57 | 7.04 | 8.68 | 9.63 | 10.77 | 41.35 | |
| 1945 | 5.32 | 9.29 | na * | na * | na * | na * | na * | * | 9 days missing data in October |
| 1946 | 1.72 | 3.00 | 3.97 | 8.16 | 7.71 | 12.93 | 21.18 | * | 9 days missing data in January |
| 1947 | 3.55 | 5.34 | 9.31 | 15.63 | 19.00 | 19.43 | 17.52 | 62.77 | |
| 1948 | 4.92 | 7.53 | 8.56 | 8.12 | 10.10 | 12.82 | 16.78 | 68.42 | |
| 1949 | 3.97 | 3.42 | 6.69 | 7.78 | 9.98 | 13.67 | 12.21 | 49.70 | |
| 1950 | 4.09 | 6.17 | 8.47 | 12.43 | 14.17 | 18.24 | 17.62 | 72.54 | |
| 1951 | 2.66 | 5.47 | 8.68 | 10.55 | 14.51 | 14.23 | 13.19 | 56.03 | |
| 1952 | 2.68 | 1.44 | 1.36 | 2.12 | 2.92 | 2.94 | 6.37 | 32.93 | |
| 1953 | 2.77 | 5.35 | 8.35 | 9.35 | 12.49 | 15.03 | 18.15 | 71.73 | |
| 1954 | 5.23 | 6.85 | 7.26 | 6.32 | 7.13 | 9.22 | 10.68 | 53.00 | |
| 1955 | 4.41 | 3.39 | 7.71 | 12.14 | 12.77 | 17.22 | 17.95 | 63.07 | |
| 1956 | 2.04 | 4.19 | 5.93 | 12.25 | 12.84 | 12.13 | 16.20 | 52.39 | |
| 1957 | 2.52 | 3.19 | 3.82 | 6.76 | 10.14 | 10.76 | 10.28 | 50.38 | |
| 1958 | 1.76 | 3.20 | 5.20 | 6.81 | 12.56 | 16.34 | 19.48 | 57.71 | |
| 1959 | 4.76 | 9.80 | 11.85 | 13.13 | 11.77 | 15.37 | 19.79 | 66.72 | |
| 1960 | 4.60 | 5.25 | 6.62 | 9.16 | 12.46 | 19.00 | 19.44 | 57.99 | |
| 1961 | 2.23 | 3.37 | 5.61 | 6.25 | 7.69 | 9.26 | 8.82 | 59.29 | |
| 1962 | 5.21 | 6.73 | 8.63 | 8.19 | 10.36 | 16.28 | 15.25 | 54.89 | |
| 1963 | 3.50 | 2.82 | 3.88 | 8.03 | 12.49 | 16.46 | 18.22 | 55.83 | |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1964 | 5.94 | | 8.67 | | 9.65 | | 8.53 | | 11.13 | | 13.67 | | 14.07 | | 70.26 | | |
| 1965 | 4.85 | | 4.45 | | 5.74 | | 5.52 | | 8.07 | | 10.45 | | 10.61 | | 48.09 | | |
| 1966 | 1.78 | | 3.21 | | 4.13 | | 7.25 | | 10.10 | | 12.75 | | 16.74 | | 54.89 | | |
| 1967 | 2.34 | | 2.80 | | 6.44 | | 10.63 | | 11.00 | | 11.50 | | 10.50 | | 51.40 | | |
| 1968 | 7.96 | | 9.99 | | 11.28 | | 9.03 | | 12.40 | | 13.59 | | 15.59 | | 66.26 | | |
| 1969 | 0.95 | | 7.69 | | 8.99 | | 9.51 | | 11.69 | | 6.26 | | 9.88 | | 52.91 | | |
| 1970 | 4.17 | | 4.51 | | 5.89 | | 8.51 | | 10.03 | | 11.43 | | 15.44 | | 55.94 | | |
| 1971 | 5.26 | | 7.29 | | 8.52 | | 10.94 | | 11.23 | | 11.61 | | 14.98 | | 64.36 | | |
| 1972 | 3.13 | | 8.07 | | 7.63 | | 8.60 | | 9.64 | | 7.14 | | 9.22 | | 71.13 | | |
| 1973 | 1.22 | | 4.19 | | 6.66 | | 8.87 | | 13.62 | | 15.00 | | 18.05 | | 52.99 | | |
| 1974 | na | * | 1.21 | | 1.38 | | 2.49 | | 4.79 | | 11.62 | | 15.21 | | * | | 26+ days missing data in July |
| 1975 | 5.62 | | 5.17 | | 8.34 | | 11.31 | | 16.01 | | 19.72 | | 23.09 | | 76.39 | | |
| 1976 | 5.77 | | 5.90 | | 3.37 | | 3.93 | | 3.69 | | 4.83 | | 6.36 | | 43.73 | | |
| 1977 | 4.41 | | 8.04 | | 8.34 | | 7.43 | | 11.17 | | 10.96 | | 19.55 | | 50.19 | | |
| 1978 | 7.80 | | 9.83 | | 9.09 | | 8.54 | | 7.96 | | 9.49 | | 12.01 | | 47.57 | | |
| 1979 | 3.88 | | 4.28 | | 4.37 | | 7.98 | | 5.37 | | 6.17 | | 16.15 | | 54.16 | | |
| 1980 | 3.47 | | 4.37 | | 5.54 | | 5.10 | | 11.31 | | 20.10 | | 25.03 | | 68.87 | | |
| 1981 | 1.06 | | 4.52 | | 9.65 | | 11.14 | | 12.42 | | 11.98 | | 12.46 | | * | | 26+ days missing data in March |
| 1982 | 4.62 | | 5.65 | | 5.46 | | 9.15 | | 8.21 | | 11.49 | | 15.49 | | 58.57 | | |
| 1983 | 6.51 | | 6.86 | | 5.91 | | 7.40 | | 11.05 | | 13.75 | | 17.50 | | 59.20 | | |
| 1984 | 1.02 | | 1.68 | | na | * | na | * | na | * | na | * | na | * | * | | 26+ days missing data in Oct. and Nov. |
| 1985 | 4.08 | | 4.68 | | 3.74 | | 11.79 | | 14.67 | | 16.55 | | 17.52 | | * | | 26+ days missing data in January |
| 1986 | 1.99 | | 4.45 | | 4.45 | | 8.33 | | 9.56 | | 16.72 | | 17.85 | | 54.79 | | |
| 1987 | 1.30 | | 1.73 | | 1.34 | | 1.64 | | 2.82 | | 3.67 | | 11.03 | | 39.60 | | |
| 1988 | 0.78 | | 3.83 | | 5.13 | | 7.45 | | 13.24 | | 14.84 | | 15.34 | | 53.73 | | |
| 1989 | 2.31 | | 1.97 | | 2.75 | | 4.00 | | 8.99 | | 10.49 | | 14.29 | | 50.24 | | |
| 1990 | 3.40 | | 3.23 | | 6.67 | | 9.99 | | 17.59 | | 24.37 | | 24.33 | | 71.03 | | |
| 1991 | 2.41 | | 1.95 | | 1.78 | | 2.20 | | 6.23 | | 11.78 | | 15.16 | | 54.32 | | |
| 1992 | 1.90 | | 3.21 | | 3.32 | | 5.59 | | 9.42 | | 11.58 | | 14.05 | | 47.91 | | |
| 1993 | 3.21 | | 0.98 | | 3.36 | | 4.35 | | 4.52 | | 7.11 | | 9.47 | | 45.00 | | |
| 1994 | 3.81 | | 3.53 | | 3.93 | | 8.92 | | 8.59 | | 14.26 | | 15.48 | | 52.91 | | |
| 1995 | 3.61 | | 4.52 | | 8.22 | | 8.25 | | 13.74 | | 19.98 | | 19.72 | | 56.76 | | |
| 1996 | 3.65 | | 4.27 | | 6.38 | | 11.80 | | 13.25 | | 18.46 | | 20.07 | | 72.48 | | |
| 1997 | 2.13 | | 5.00 | | 8.90 | | 11.37 | | 11.81 | | 12.61 | | 9.70 | | * | | 26+ days missing data in January |
| 1998 | na | * | na | * | na | * | 5.29 | | 9.21 | | 17.23 | | 20.02 | | * | | 26+ days missing data in Jan, Apr, and Aug |
| 1999 | 3.14 | | 2.29 | | 3.59 | | 5.08 | | 12.19 | | 17.86 | | 20.63 | | 63.28 | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 2.63 | 4.06 | na * | na * | na * | na * | na * | * | 26+ days missing data Mar. Apr. May and Oct. |
| 2001 | na * | 4.84 | 6.77 | 7.21 | 13.11 | 18.38 | 22.66 | * | 26+ days missing data in July |
| 2002 | 1.53 | 1.25 | 2.50 | 2.24 | na * | na * | na * | * | 26+ days missing data in November |
| 2003 | 1.57 | 2.76 | 4.21 | 12.94 | 12.38 | 17.74 | 20.38 | 58.66 | |
| 2004 | 10.77 | 12.29 | 13.01 | 8.66 | 7.71 | 10.59 | 13.95 | 56.68 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Mean | 3.61 | 4.80 | 6.17 | 8.25 | 10.69 | 13.24 | 15.41 | 56.52 |
| Max | 10.77 | 12.29 | 13.01 | 15.63 | 19.40 | 24.37 | 25.03 | 76.39 |
| Year | 2004 | 2004 | 2004 | 1947 | 1934 | 1990 | 1980 | 1975 |
| Min | 0.78 | 0.98 | 1.34 | 1.64 | 2.82 | 2.94 | 6.36 | 32.93 |
| Year | 1998 | 1993 | 1987 | 1987 | 1987 | 1952 | 1976 | 1952 |
| Years | 70 | 72 | 68 | 70 | 69 | 69 | 69 | 60 |

| | | | |
|---|---|---|---|
| 2 month period- | | < 50% | percentage of average for all years |
| | | < 75% | percentage of average for all years |
| | | > 125% | percentage of average for all years |

* indicates missing data see comment column

The data above was derived from the Western Regional Climate Center web site data.

Original data is available at the web address below under Period of Record - Precipitation -

Monthly Precipitation Listings - Monthly Totals http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?waland

*This page intentionally left blank.*

# APPENDIX I

## Identification and Evaluation of Habitat Enhancement Opportunities for Rock Creek

*This page intentionally left blank.*

*FINAL*

# Identification and Evaluation of Habitat Enhancement Opportunities for Rock Creek

*Prepared for:*

**City of Kent**

*Prepared by:*

**R2 Resource Consultants, Inc.**
15250 NE 95th Street
Redmond, Washington 98052-2518

June 2005

# CONTENTS

1. INTRODUCTION .....1

2. METHODS .....2

3. RESULTS .....4

3.1 REACH 1 .....4

3.2 REACH 2 .....5

3.3 REACH 3 .....5

3.4 REACH 4 .....7

3.5 REACHES 5, 6, AND 7 .....7

3.6 REACH 8 .....9

3.7 REACHES 9 AND 9B .....10

3.8 REACHES 10, 11, 12, AND 13 .....10

3.9 ROCK CREEK UPSTREAM OF THE CITY OF KENT WATERSHED .....11

4. RECOMMENDATIONS FOR HABITAT RESTORATION AND ENHANCEMENT .....12

4.1 R1-1. PASSAGE IMPROVEMENT AT THE MOUTH OF ROCK CREEK .....14

4.2 R1-2. CONNECTION/ENHANCEMENT OF REACH 1 WETLAND COMPLEX .....18

4.3 R8-1. SUMMIT-LANDSBURG ROAD CULVERT REPLACEMENT .....21

4.4 R12-1. LWD PLACEMENT IN REACH 12 .....22

4.5 R10-1. LWD PLACEMENT IN REACH 10 .....24

4.6 FENCING AROUND LOWER PORTION OF CITY OF KENT WATERSHED PROPERTY .....25

4.7 R2-1. ENHANCEMENT OF REACH 2 POND/WETLAND COMPLEX.....25

5. LITERATURE CITED .....28

## FIGURES

Figure 1. Map of the Rock Creek Drainage. Washington, depicting stream reaches surveyed during spawning surveys completed in 2003-2004. ....3

Figure 2. Looking downstream at a large log jam located in Reach 3 of Rock Creek at a flow of approximately 16 cfs on February 3, 2005. ....6

Figure 3. Small bank failure that has introduced both fines and gravel to Reach 5 of Rock Creek, February 2, 2005. ....8

Figure 4. Profile of Rock Creek bed and water surface elevation at the confluence with the Cedar River on February 3, 2005. Rock Creek flow of 16 cfs; Cedar River flow of 382 cfs. ....15

Figure 5. Looking upstream at the confluence of Rock Creek from the Cedar River on at a flow of 3.1 cfs. Photo from video footage. ....15

Figure 6. Conceptual plan view design sketch of a series of Rock weirs that could be constructed at the mouth of Rock Creek to improve low flow fish passage. ....16

Figure 7. Conceptual section-view design sketch of the general configuration rock weirs that could be constructed at the mouth of Rock Creek to improve low flow fish passage. ....16

Figure 8. Photograph of the pond adjacent to Reach 1 of lower Rock Creek on February 3, 2005. Photo taken looking southeast across the pond and elevated trail towards Rock Creek. ....18

Figure 9. Section (a) and plan view (b) sketches of the suggested Rock Creek Reach 1 pond connection project. ....19

Figure 10. Looking upstream at the Summit Landsburg Road crossing on Rock Creek, February 3, 2005 at a flow of 15 cfs. ....22

Figure 11. Looking upstream in Reach 12 of Rock Creek, at suggested location of LWD enhancement, February 3, 2005 at a flow of 15 cfs. ....23

Figure 12. Section (a) and plan view (b) sketches of the suggested Rock Creek Reach 12 LWD enhancement. ....24

Figure 13. Existing pond wetland complex adjacent to Reach 2, looking east from Rock Creek on February 3, 2005. Rock Creek flow of 15 cfs. ....26

Figure 14. Conceptual plan view design sketch of the suggested reconfiguration of the pond and wetland complex associated with Reach 2 of lower Rock Creek. ....26

# TABLES

Table 1. Summary and prioritization of potential restoration and enhancement opportunities identified on Rock Creek. .....13

# 1. INTRODUCTION

The City of Kent is developing a Habitat Conservation Plan (HCP) covering the Clark Springs Water Supply Facility. The plan will be submitted to the U.S. Fish and Wildlife Service and NOAA Fisheries (the Services) for purposes of obtaining an Incidental Take Permit (ITP) to cover the City's activities related to the facility. The Services requested that the City evaluate, and to the extent possible, identify potential habitat enhancement/restoration projects that could be used as mitigation for project operations. This evaluation focuses on opportunities for enhancement/restoration of physical habitats. Instream flow issues are being assessed separately and are not addressed by this report.

The Clark Springs Water Supply Facility is located in the Rock Creek basin; Rock Creek is a tributary to the Lower Cedar River and is considered by many to provide some of the best remaining tributary habitat in the Cedar River Watershed (WRIA 8 Steering Committee 2004). The HCP Action Area will include the 320-acre City of Kent watershed property that surrounds the Clark Springs Water Supply Facility and the entire length of Rock Creek extending from the eastern end of the watershed property (at RM 2.7) to the confluence with the Cedar River.

In response to the Services request, the City of Kent contracted with R2 Resource Consultants (R2) to complete a habitat enhancement feasibility evaluation in the Rock Creek basin. On February 3, 2005 R2 completed a reconnaissance survey of Rock Creek with the goal of identifying potential restoration actions that could be implemented to restore or improve fish habitat for covered species (Chinook, coho, and sockeye salmon and steelhead, cutthroat, and resident trout) in Rock Creek. The survey was intended to be "ownership blind" and aimed at identifying all potential restoration opportunities rather than just those that could be directly undertaken by the City of Kent as part of the HCP. However, the importance of ownership was acknowledged when prioritizing potential restoration activities to ensure that actions proposed as potential conservation measures under the HCP have a reasonable expectation of being successfully implemented.

This report describes the results of the reconnaissance survey. Section 2 describes the survey methods. Section 3 provides a brief description of potential restoration opportunities by reach. Section 4 presents recommendations and design concepts for restoration and enhancement projects that could be implemented under the HCP. This information is intended solely to support a preliminary evaluation of the technical feasibility and relative biological benefits of the recommended projects and does not represent complete project design.

# 2. METHODS

The reconnaissance survey was conducted by a fluvial geomorphologist and fish biologist/engineer with experience in developing habitat restoration plans and projects. Biologists familiar with the Rock Creek system and an engineer specializing in the design and implementation of projects aimed at restoration of fish passage provided additional support.

The survey initiated at the mouth of Rock Creek and continued upstream through the City of Kent watershed property. Spot checks of channel conditions were conducted at stream crossings at 262nd Avenue SE and 268th Avenue SE, and at the location where SR 516 (Kent-Kangley Road) crosses Georgetown Creek. Information on restoration opportunities was collected by reach using reach designations developed for spawning surveys (Figure 1).

During the survey, information on general habitat conditions, potential fish passage concerns and potential habitat restoration opportunities was recorded. Where necessary, basic survey data were collected using a hand level or auto level and stadia rod. The location of each feature of interest within the reach was recorded based on the measured distance from the nearest downstream reach break as recorded using a hip-chain. Photographs were taken to document restoration opportunities and areas of concern, and to support development of design concepts.

Physical habitat conditions were evaluated qualitatively for this assessment, and focused primarily on the general influence of anthropogenic activities. Several reports that provide a more quantitative evaluation of habitat conditions in some or all of the survey are available (Jones and Stokes 1993; Pentec 2001). A detailed barrier assessment at each crossing structure was beyond the scope of this assessment. The evaluation of fish passage relied on limited survey data and a visual assessment by individuals familiar with state passage criteria to determine whether existing passage structures appeared to be in compliance with current WDFW passage criteria (WDFW 2003). The survey was conducted at a relatively high flow (15 cfs), thus identification of areas where physical habitat conditions gave rise to low flow passage concerns relied on general channel configuration and information and photos provided by biologists who had seen the areas at low flow.

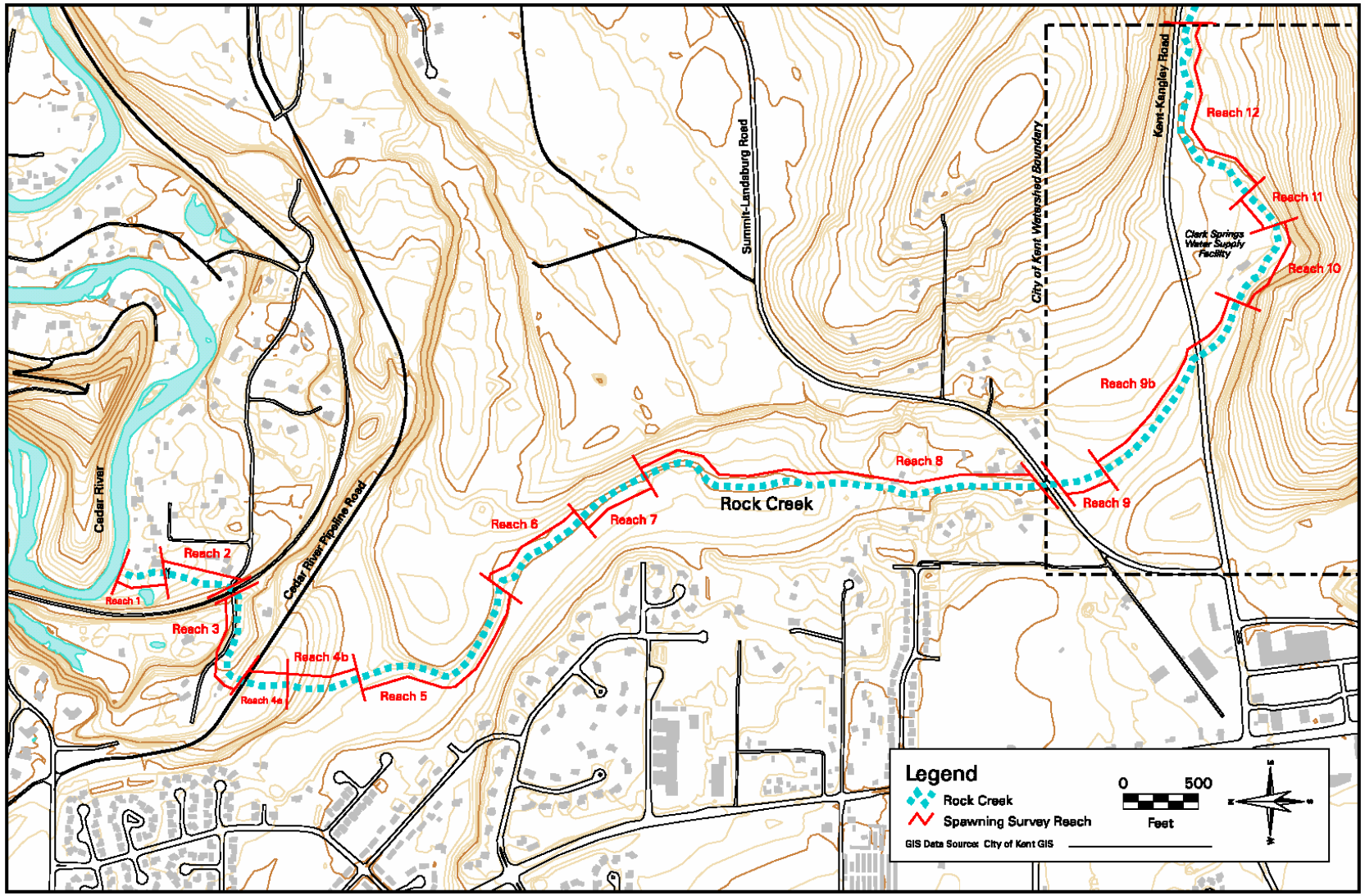



Figure 1. Map of the Rock Creek Drainage. Washington, depicting stream reaches surveyed during spawning surveys completed in 2003-2004.

# 3. RESULTS

Habitat conditions and restoration opportunities identified during the reconnaissance survey are reported below for each reach. The distribution of reaches and other key infrastructures are depicted in Figure 1.

## 3.1 REACH 1

Reach 1 is a roughly 330-foot-long segment of channel that has an overall gradient of approximately 2 to 4 percent. Reach 1 of Rock Creek flows across alluvial sediments deposited by the Cedar River, thus the channel bed consists primarily of rounded gravel and cobble size material with occasional boulders. Historical evidence concerning the alignment of the mouth of Rock Creek is mixed. USGS topographic maps constructed in 1973 suggest Rock Creek flowed east from Reach 2 joining the Cedar River approximately 1,500 feet upstream of the current confluence. However, maps from 1897 and 1900 suggest the current location is similar to its location during that early time period. Given the valley configuration and direction of flow in the Cedar River, the 1973 alignment appears unlikely and would most likely have occurred only if Rock Creek had intersected a former side channel of the Cedar River. Natural channels rarely flow upstream into mainstem rivers. Regardless of its historical alignment, the channel in Reach 1 is quite steep at its confluence with the Cedar River (approximate gradient 7 percent), and upstream passage is a concern at low flows.

Four potential restoration/enhancement opportunities were identified in Reach 1:

R1-1. Improving low flow passage at the confluence with the Cedar River.

R1-2. Connecting a small pond wetland on the west bank to the Rock Creek mainstem to provide winter rearing habitat.

R1-3. Riparian and stream bank restoration on the private property located on the east bank.

R1-4. In wide shallow areas with a uniform bed cross-section, countersink logs that partially span the channel to concentrate low flows and promote thalweg scour while not significantly affecting high flow water levels.

## 3.2 REACH 2

Reach 2 is a 450-foot-long segment of channel that extends from the footbridge to the box culvert at the SE 248th Street stream crossing. The gradient of Reach 2 is approximately 2.0 percent. As for Reach 1, this section of Rock Creek flows across alluvium deposited by the Cedar River, and has bed substrate that consists primarily of gravel and cobble. Just above the footbridge, the channel splits around a small mid-channel island. An open water wetland that remains connected to the channel at most flows is located on the east bank. The substrate in this wetland currently consists of at least 2-feet of organic muck.

Upstream of the wetland there is a series of recently constructed habitat enhancement features. Most of the wood associated with these features is elevated above the channel. Additional large woody debris (LWD) was delivered to the channel by a major windstorm in 2003; LWD is abundant in most of Reach 2. Where LWD is absent, the channel tends to be straight with relatively coarse substrate. Large woody debris that was level with the channel bed could enhance sediment storage, although such measures would need to carefully consider the potential for increased flooding to ensure protection of private property.

Two potential restoration opportunities were identified in Reach 2:

R2-1. Enhancement of the existing off-channel habitat/open water wetland located on the east bank of Rock Creek just upstream of the footbridge.

R2-2. Placement of countersunk logs or rock weirs to trap gravel and enhance spawning habitat where flow diverges downstream of narrow runs.

## 3.3 REACH 3

Reach 3 is a 656-foot-long segment of channel that extends from the SE 248th Street stream crossing to the Seattle Pipeline stream crossing. An old culvert at the SE 248th Street crossing that was perceived to be a potential fish barrier at some stream flows was replaced in 2003. The new crossing structure culvert is a bottomless concrete box and appears to meet current WDFW passage criteria. Reach 3 represents an area of transition from the Cedar River floodplain to a narrow ravine cut through quaternary glacial sediments. The overall gradient is approximately 2.2 percent, however several short sections with significantly higher gradients in association with large logjams were noted (Figure 2). Individual large logs and jams were noted to have accumulated extensive deposits of mobile gravels, however the majority of this reach is characterized by cobble to small boulder-size framework materials.

The WRIA 8 Conservation Plan (WRIA 8 Steering Committee 2004) recommended that riparian enhancement be implemented in Reach 3 to offset trees blown down during the 2003 windstorm. Recent plantings were observed in Reach 3 during the survey, primarily associated with the slope below the Seattle Water Pipeline. No additional restoration opportunities were identified in Reach 3. Large woody debris is abundant due to the recent blowdown. Wood clearly functions to store sediment, however even very large pieces of LWD are not observed to form large deep pools. Wide, shallow areas where low flows could interfere with upstream passage were noted, although most covered short-distances (less than 100 feet). Such areas form naturally in response to changes in hydraulics and sediment storage that result from LWD entering the channel, thus treatment of any individual site would provide a temporary fix at best, and would likely require ongoing maintenance.

Figure 2. Looking downstream at a large log jam located in Reach 3 of Rock Creek at a flow of approximately 16 cfs on February 3, 2005.

## 3.4 REACH 4

Reach 4 is an 830-foot-long segment of channel that extends upstream from the Seattle Water Pipeline stream crossing. This crossing consists of a box culvert and two circular overflow culverts that convey a small amount of water even at low flows. The box culvert has baffles and is probably passable by adult and juvenile salmonids under most flows; however, splitting the flow into multiple culverts may limit passage at low flows.

Reach 4 has an overall gradient of about 2.0 percent. Short areas with locally higher gradients were observed. Overall, LWD was abundant, and has functioned to store sediment, although as for Reach 3 it was not observed to form deep pools. Reach 4 is semi-alluvial, with substrate consisting of stable sub-angular cobble and small boulders. Smaller sediments are mobile, and numerous patches of gravel are present. However, large accumulations of gravel and cobble deep enough to support Chinook spawning were less common than downstream.

With the exception of potential passage issues associated with the Seattle Pipeline culvert at the beginning of the reach, no restoration opportunities were identified in Reach 4. Habitat and riparian vegetation are in good condition. The City of Seattle is currently evaluating whether or not improvements are necessary at the pipeline crossing (Chinook Engineering 2004), thus that action was not identified as a restoration opportunity that could be undertaken by the City of Kent as part of the Clark Springs Water Facility HCP.

## 3.5 REACHES 5, 6, AND 7

Habitat conditions in Reaches 5, 6 and 7 are similar to those described for Reach 4. The primary difference is valley configuration, which is narrow with steeper sideslopes in Reaches 5 and 7, and moderately confined in Reach 6. Increased levels of sand and very fine gravel were noted, and a number of localized input sites consisting of eroding banks or small failures were identified (Figure 3). The riparian zone is intact, thus these features represent natural sites of sediment input, and are not considered an impact that should be rehabilitated. Such features were also noted to be sources of small gravel that formed some of the better spawning patches with identifiable redds from recent spawning of sockeye or coho salmon. No obvious restoration opportunities were noted in Reach 5, 6 or 7.

Figure 3. Small bank failure that has introduced both fines and gravel to Reach 5 of Rock Creek, February 2, 2005.

## 3.6 REACH 8

Reach 8 consists of a long low gradient forested wetland complex. Reach 8 flows across the broad flat glacial outwash deposit characteristic of the upper Rock Creek valley, and has an overall gradient of less than 1 percent. The outwash deposits are glacial rather than alluvial in nature and thus naturally contain a high proportion of sand and fine sediment as compared to downstream reaches. Deep deposits of fine sediment supporting aquatic vegetation were common. Spawning areas consisting of gravel to small cobble were observed frequently, although they appeared somewhat finer than is typically preferred by Chinook salmon. Because of the high levels of fine sediment, spawning gravels typically occur where localized flow obstructions concentrate flow and develop swift enough velocity to flush and throughput fines.

Habitat conditions in the lower portion of Reach 8 are good, with an intact riparian zone. However, residential development along the upstream part of this reach does affect habitat and offers some opportunities for restoration or enhancement. Reestablishment of riparian vegetation along the right (east) bank would increase cover and shade as well as providing bank stabilization. Banks are currently hardened with a variety of materials including hand placed cobble, timbers, and small boulders (see cover photo). Several pieces of LWD were observed to increase the habitat complexity in the upstream end of Reach 8. However, this material consisted largely of 8-12 inch diameter alder recruited during the 2003 windstorm and is not expected to persist in the stream for more than a few years.

Reach 8 ends at the Summit-Landsburg Road. The existing crossing structure consists of three 24-inch diameter culverts embedded in masonry/concrete. At a flow of approximately 15 cfs during the survey, the culvert outlets were perched approximately 6 inches above the water surface on the downstream side of the crossing. Although the structure is passable for adult salmonids, as evidenced by spawning coho and sockeye observed in upstream reaches, it does not meet WDFW passage criteria and could represent a barrier at low flows due to shallow depths and high velocities that result from splitting the flow through three culverts.

Three potential habitat restoration opportunities were identified in Reach 8:

R8-1. Replacement of the crossing structure at the Summit-Landsburg Road.

R8-2. Re-establishment of native riparian vegetation, including shrubs or small trees on residential properties bordering the stream.

R8-3. Strategic placement of wood structures to concentrate flow and enhance localized flushing of fine sediments to improve spawning in the same section of channel as Measure 8-2.

## 3.7 REACHES 9 AND 9B

Reaches 9 and 9b extend from Summit-Landsburg Road upstream past SR 516 (Kent-Kangley Road) to the flow augmentation pipe and are located entirely within the City of Kent watershed property. Reach 9 represents a continuation of the forested wetland habitat first encountered in Reach 8. The channel is multi-threaded with abundant fine sediment except in areas where locally high gradient or flow obstructions result in velocities that are sufficient to keep the bed clear of fine sediment. Riparian zones on both sides of the stream are intact but consist primarily of young deciduous trees and shrubs. The complex channel offers excellent rearing habitat for all species of salmonids. Reach 9b is upstream of Reach 9, and consists of a steeper gradient single channel flowing from a lower gradient, split channel wetland complex upstream.

No opportunities for enhancement of physical habitat were noted in Reach 9. However, due to its location between two heavily used local roads, littering and illegal dumping have introduced trash to Reaches 9 and 9b. Actions to reduce introduction of trash to Rock Creek would improve habitat appearances in Rock Creek and help protect it from potentially serious water quality impacts.

R9-1. Fence watershed property in the vicinity of Reach 9 to reduce littering and illegal dumping.

## 3.8 REACHES 10, 11, 12, AND 13

Reaches 10 through 13 traverse the City of Kent watershed property upstream from the augmentation pipe, extending for approximately one mile to the eastern property boundary. Habitat in these reaches is similar, consisting primarily of a multi-threaded channel that flows through scrub-shrub wetlands interspersed with short stretches where the channel is bordered by mixed forest on one or both sides. A portion of the riparian corridor is affected by the presence and maintenance of transmission lines owned by the Bonneville Power Administration.

Substrate is a mixture of loose, unconsolidated sand and gravel. Areas of dense shrubs provide abundant cover where water flows around and through roots and trailing branches. In areas where shrubs are absent the channel is approximately 30 feet wide with a fairly uniform cross

section. Clean gravels occur only where local flow obstructions result in velocities that are sufficient to keep the bed surface clear of fine sediment. Habitat complexity in these areas is provided primarily by LWD.

Two restoration opportunities were noted in reaches 10-13. Both focused on portions of straight uniform channels that would benefit from LWD placement.

R10-1. Addition of individual pieces of LWD to the section of channel immediately downstream of the footbridge would enhance spawning and rearing habitat by increasing hydraulic complexity and cover.

R12-1. Addition of individual pieces of LWD to the section of channel immediately near the maintenance road and monitoring wells would enhance spawning and rearing habitat by increasing hydraulic complexity and cover. Existing fallen conifers spanning the channel in this area could be cut and dropped into the stream.

## 3.9 ROCK CREEK UPSTREAM OF THE CITY OF KENT WATERSHED

Spot checks were made of habitat conditions upstream of the City of Kent watershed property. At 262nd Avenue SE, located at RM 2.8, approximately 0.10 miles upstream of the eastern watershed boundary, flows were noticeably lower than within the surveyed reach. At 268th Avenue SE (RM 3.36) flows in Rock Creek were just a trickle. Inflows in Georgetown Creek just upstream of the confluence with Rock Creek were also low.

As a result of the intermittent nature of flow in the upstream reaches, direct manipulation of physical habitat in the upper watershed would provide minimal benefits for covered species. Instead, efforts should focus on protection and restoration of critical watershed functions such as riparian zones, sediment inputs, water quality and groundwater recharge. Several recent documents contain recommendations for both general strategies and specific actions (Friends of Rock Creek 2004; WRIA 8 Steering Committee 2004).

## 4. RECOMMENDATIONS FOR HABITAT RESTORATION AND ENHANCEMENT

The specific goal of this assessment was to identify habitat enhancement or restoration activities that could be undertaken by the City of Kent as part of the Clark Springs Water Supply Facility HCP. To this end, potential habitat restoration opportunities identified in Section 3 were prioritized based on the potential benefits to species covered under the HCP as well as the level of certainty that such projects could be implemented as Conservation Measures under the HCP. Overall, a total of 12 potential specific habitat restoration opportunities were identified for Rock Creek.

Restoration opportunities were prioritized based on a combination of biological benefits and land ownership (Table 1). Criteria used to prioritize biological benefits were:

- Projects that would benefit multiple species and lifestages, including ESA-listed Chinook salmon, or that improved access to a large extent of stream (i.e., greater than 1-mile) for one or more salmonid species were assumed to have high benefits.
- Projects that would benefit at least one species or lifestage proposed for coverage under the HCP, or that improved access to a moderate length of habitat (500-feet to 1 mile) were assumed to have moderate benefits.
- Projects that would result in localized improvements within a relatively short section of stream (i.e., less than 500 feet) were assumed to have limited benefits.

Criteria used to assign certainty are as follows:

- Projects located on lands owned by the City of Kent were assigned a high level of certainty.
- Projects located on other public lands (County, State or Federal) were assigned a moderate level of certainty.
- Projects located on privately owned lands were assigned a low level of certainty.

Design concepts were developed for each potential opportunity that was assigned a high or moderate level of certainty. Those design concepts are presented below. In addition, a design concept is included for one project that would have high benefits, but that is located on private lands and was thus assigned a low level of certainty. No design concepts were developed for projects deemed to have only moderate or localized beneficial effects and assigned a low level of

Table 1. Summary and prioritization of potential restoration and enhancement opportunities identified on Rock Creek.

| Reach | Project # | Priority | Title | Ownership | Potential Benefits | Level of Certainty | Cost Range |
|---|---|---|---|---|---|---|---|
| 1 | R1-1 | 1 | Upstream passage at mouth | King County-west<br>Private - east | High | Moderate | $15,000-$30,000 |
| 1 | R1-2 | 2 | Connect Reach 1 wetland | King County | High | Moderate | $30,000-$50,000 |
| 2 | R2-1 | 7 | Improve Reach 2 wetland | King County | Localized | Moderate | $15,000-$25,000 |
| 8-9 | R8-1 | 3 | Culvert replacement at Summit-Landsburg Road | City of Kent;<br>County Road Right of Way? | Moderate | High | $600,000-$1,000,000 |
| 12 | R12-1 | 4 | LWD placement in Reach 12 | City of Kent | Localized | High | $10,000-$15,000 |
| 10 | R10-1 | 5 | LWD placement in Reach 10 | City of Kent | Localized | High | $15,000-$25,000 |
| 9 | R9-1 | 6 | Fence watershed property | City of Kent | Low | High | $10,000-$20,000 |
| 1 | R1-3 | 8 | LWD to concentrate flow | Private | Localized | Low | – |
| 2 | R2-2 | 9 | LWD to trap gravel | Private | Localized | Low | – |
| 1 | R1-4 | 10 | Riparian restoration Reach 1 | Private | Localized | Low | – |
| 8 | R8-2 | 11 | Riparian restoration Reach 8 | Private | Localized | Low | – |
| 8 | R8-3 | 12 | LWD placement Reach 8 | Private | Localized | Low | – |

certainty. Such projects could be supported by contributing funds to a general watershed enhancement fund that provides grants to other entities. However, given the low level of certainty that such actions could be implemented under the HCP, they are not considered viable options for specific conservation measures at this time.

Design and approximate costs for seven opportunities are presented below. Opinions of probable costs included in this document are intended for planning purposes only and assume that landowner support is readily obtained and that limited consultation will be required during the permitting process. Additional site reconnaissance and design efforts are recommended to refine the costs shown. Costs are presented in 2005 dollars, based on an Engineering News Record Construction Cost Index of 7297.58 for February 2005 (http://env.construction.com).

Restoration opportunities located on private lands were identified where they were encountered and ranked based on their perceived benefits to covered species. However, no design concepts were developed for those sites because the City of Kent cannot ensure that such projects would be implemented as part of the HCP.

## 4.1 R1-1. PASSAGE IMPROVEMENT AT THE MOUTH OF ROCK CREEK

The mouth of Rock Creek is currently perched approximately 3 feet above the confluence with the Cedar River at lower flows, resulting in a 40-foot long section composed of large cobble and boulders that has a gradient of 7 percent (Figure 4). Although the area is passable at moderate to high flows, during low flows water from Rock Creek flows through and around the boulders, potentially impeding the upstream passage of adult and juvenile fish due to shallow depths, lack of jumping pools, and high velocities (Figure 5).

Improvement of passage at the mouth of Rock Creek could be accomplished by constructing a series of low rock weirs with a center slot that concentrates flow, especially during low flow periods. Concentrated flow would provide sufficient depth for fish to move upstream, while the weirs will act to slightly pond water and provide resting areas for upstream migration. Swift velocity in the concentrated flow path is not anticipated to be a concern because of the relatively short length of the section.

Figures 6 and 7 present conceptual design sketches of the recommended approach for improving upstream fish passage at the mouth of Rock Creek. Construction of the weirs would require imported boulders with a diameter of approximately 1.5- to 2-feet. The actual number of weirs

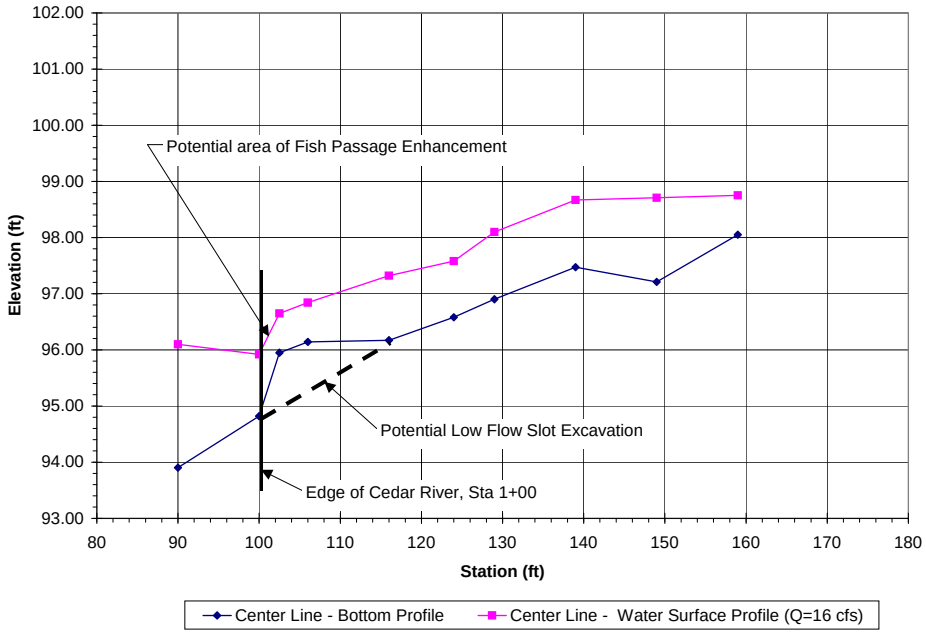



Figure 4. Profile of Rock Creek bed and water surface elevation at the confluence with the Cedar River on February 3, 2005. Rock Creek flow of 16 cfs; Cedar River flow of 382 cfs.

Figure 5. Looking upstream at the confluence of Rock Creek from the Cedar River on at a flow of 3.1 cfs. Photo from video footage.

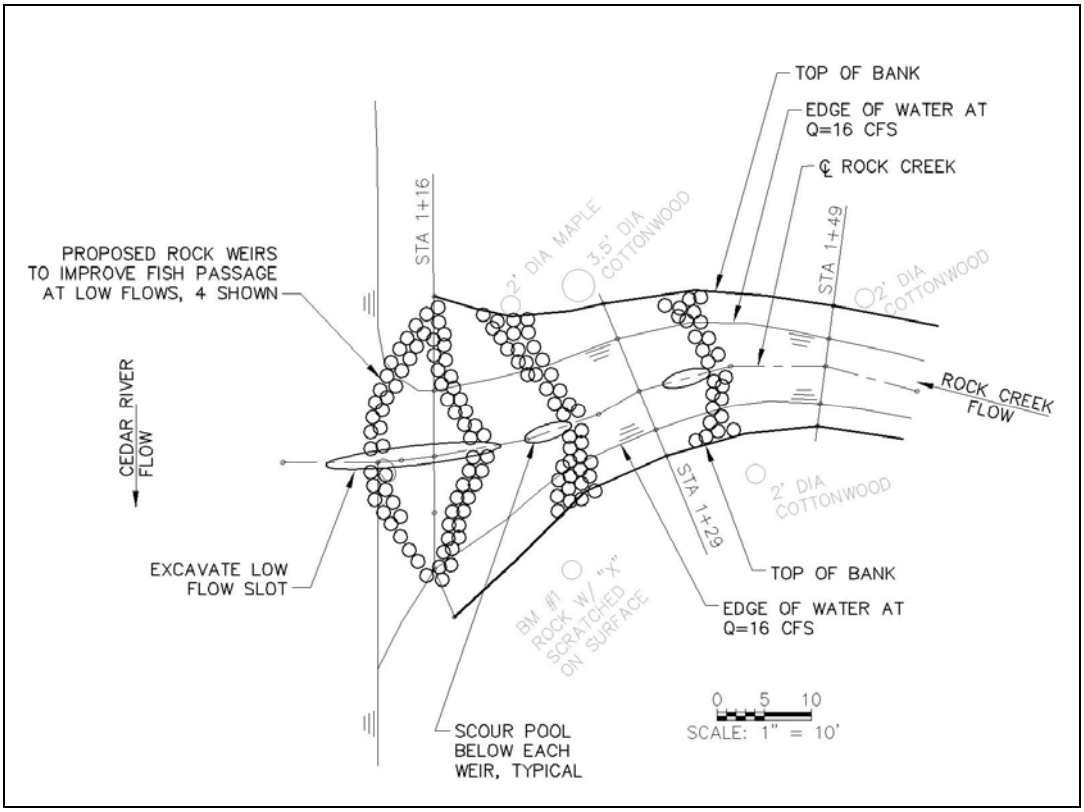



Figure 6. Conceptual plan view design sketch of a series of Rock weirs that could be constructed at the mouth of Rock Creek to improve low flow fish passage.

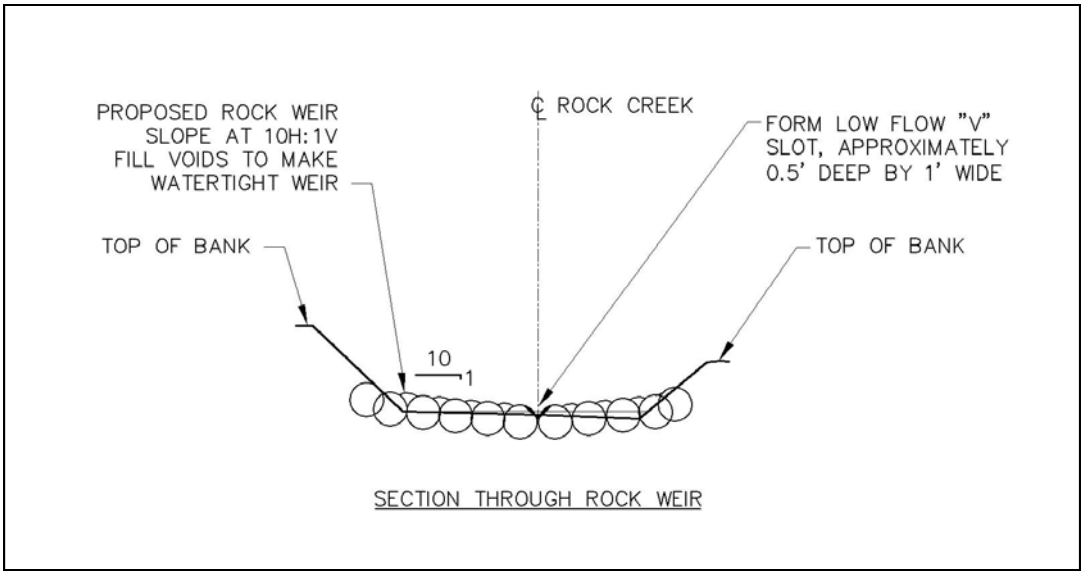



Figure 7. Conceptual section-view design sketch of the general configuration rock weirs that could be constructed at the mouth of Rock Creek to improve low flow fish passage.

constructed may vary from four to six; each weir should provide approximately 6-inches of lift. Weirs should be located at the mouth and at the bend approximately 30 feet upstream.

Boulder placement could be accomplished using a small rubber-tired track hoe and hand adjustment. Access to the site is available on the King County property on the west bank of Rock Creek via a footpath from SE 246th Street. Permission to access the site via the private property on the west bank would be helpful, but not critical. Minimal vegetation clearing would be required for access and construction. Cleared areas (if any) would be reseeded using native plants.

Estimated design, construction and permitting costs for this project are approximately $15,000-$30,000. This opinion of cost assumes that implementation of the project is supported by King County (the west bank landowner) and that a conservation easement or acquisition of additional real estate on the east bank and in the channel is not required. Costs for temporary construction and maintenance easements are also not included. For the purposes of this report, it was assumed that King County would grant easements for actions identified as desirable by the WRIA 8 Steering Committee.

The proposed project would likely require at least some level of ongoing maintenance. Rock weirs should be checked annually prior to the time when fish movement into Rock Creek generally commences to ensure that the center slots are clear and function to concentrate flow. Rock weir configuration could be affected by high flow events in either Rock Creek or the Cedar River, thus it is anticipated that extensive maintenance may be required at a frequency of approximately 10 years. Potential maintenance costs could be reduced by using larger rock or by grouting placed material in place. However, use of these techniques could increase permitting and construction costs.

An alternative to the use of rock weirs would be to construct similar structures using notched logs. Notched logs would need to be anchored and at least partly buried in the bank, thus this approach would require increased site disturbance, as well as access to the east bank property. Log weirs may require less frequent maintenance, but would eventually have to be replaced when the wood decays (assume replacement interval of approximately 10 to 25 years depending on rate of bedload corrasion).

Improvement of low flow fish passage at the mouth of Rock Creek would benefit all species that use or potentially use Rock Creek for spawning. Passage improvement would be particularly beneficial for Chinook salmon, large bodied fish that migrate upstream in the Cedar River basin to spawn during August and September when flows are typically low. Sockeye salmon also

begin spawning in the late summer and are known to heavily utilize the entire perennial length of Rock Creek.

## 4.2 R1-2. CONNECTION/ENHANCEMENT OF REACH 1 WETLAND COMPLEX

The pond and wetland complex on King County land adjacent to the west bank of Rock Creek in Reach 1 currently lacks a direct connection to Rock Creek (Figure 8). Pond and stream water surface elevations (WSE) were surveyed on February 3, 2005 at a flow of 15 cfs in Rock Creek and approximately 380 cfs in the Cedar River. At that time the pond WSE was approximately 1.5 feet lower than the WSE of Rock Creek (Figure 9a). A subsequent visit indicated there are no overflow points on the downslope berm isolating the pond from the Cedar River. No information on seasonal variations in the relationship between pond WSE and Creek WSE were available for this analysis. However, a staff gage and PVC pipe with an apparent data logger were noted in the pond during the site visit.

Figure 8. Photograph of the pond adjacent to Reach 1 of lower Rock Creek on February 3, 2005. Photo taken looking southeast across the pond and elevated trail towards Rock Creek.

Based on the limited available information, it appears that a connection could be maintained between the pond and Rock Creek during winter periods to provide winter and summer off-channel rearing habitat. A general plan view of this suggested habitat enhancement project is provided in Figure 9b.

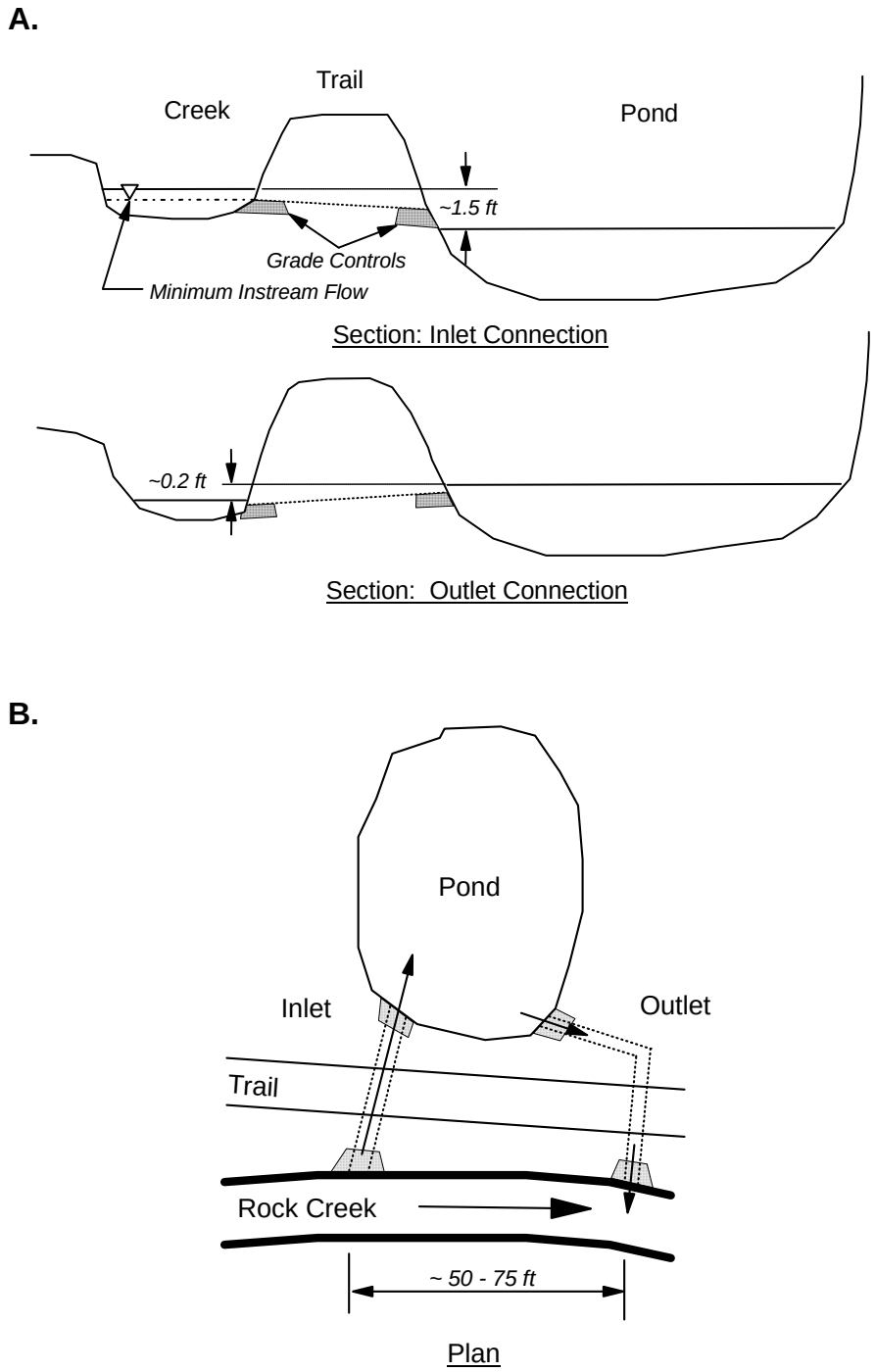



Figure 9. Section (a) and plan view (b) sketches of the suggested Rock Creek Reach 1 pond connection project.

Connection of the pond could be accomplished by excavating 1- to 2-foot wide inlet and outlet channels. If desired, access along the footpath could be maintained by installation of small footbridges. The 2 to 4 percent gradient in Rock Creek provides enough drop in head that the pond inlet and outlet would not need to be very far apart (Figure 9). Existing pond habitat could be enhanced by placement of LWD to provide hiding cover for juvenile salmonids. Based on the observed pond surface elevation and the bed elevation and WSE in Rock Creek, it appears likely a structure controlling inflows and outflows, such that inflow to the pond is cut off during low flows in Rock Creek, will be required in order to avoid dewatering the stream.

Substantial additional data are required to confirm feasibility before developing final project designs and cost estimates. Information from the existing pond WSE gage recorder should be obtained to evaluate seasonal changes in the relationship between pond WSE and stream WSE. A detailed topographic survey of the pond configuration, depth and inlet and outlet connectivity should be completed in support of project design to ensure that implementation of the project does not capture additional flow from Rock Creek during the summer and for locating the inlet and outlet. Finally, temperature and DO should be monitored through at least one summer to confirm that conditions within the pond are suitable to support salmonid rearing year round.

Access to the pond for excavation can be accomplished via the existing footpath. A small rubber tired track hoe would likely be sufficient to complete the required excavation. Minor vegetation clearing would be required.

Estimated monitoring, design, construction and permitting costs for this project are expected to require between $30,000 and $50,000. This opinion of cost assumes that implementation of the project is supported by King County (the landowner), any amount of fill needed to control the pond outlet elevation is available on-site, and that acquisition of additional real estate is not required. Costs for temporary construction and maintenance easements are not included. This project was previously identified as a potential habitat enhancement opportunity by the WRIA 8 steering committee and it is assumed that King County would support these efforts.

Enhancement of pond habitat will improve off-channel rearing habitat available to juvenile salmonids in Rock Creek. Given the proximity of this site to the Cedar River (175-ft travel distance), it is also possible that juvenile fish originating from the Cedar River could access the site, particularly during high flows. Off-channel habitats are preferred by coho salmon, but are also sometimes used by juvenile Chinook salmon in the nearby Green River (Jeanes and Hilgert 2000).

## 4.3 R8-1. SUMMIT-LANDSBURG ROAD CULVERT REPLACEMENT

Replacement of the existing stream crossing structure at the Summit-Landsburg Road would ensure unrestricted passage by all species at all flows, including movement of juvenile salmonids upstream into the wetland complex associated with Reach 9. The existing culverts at the Summit Landsburg Road do not meet current WDFW fish passage criteria, which require uninhibited upstream and downstream passage of all species and life stages, including resident trout and juvenile salmonids (WDFW 2003). The culvert outlets were perched approximately 6 inches above the water surface on February 3, 2005 at a flow of approximately 15 cfs in Rock Creek (Figure 10). The culverts may also be undersized; water backed up behind the crossing during the February 1996 flood reportedly overtopped the road and caused localized flooding (Burlingame 2005). Because of the low stream gradient and concerns about localized flooding, raising the tailwater such that the culvert outlets are backwatered at all flows is not a viable option over the long-term. However, installation of structures to raise the tailwater might be an option in the short-term provided landowner cooperation was obtained and potential flooding issues were addressed.

Recommended WDFW culvert passage criteria are intended to size crossing structures such that natural stream processes will take place within the structure. These processes include a natural graded streambed, capable of passing bedload as well as other terrestrial and aquatic species other than fish. The required “span” of the structure is typically about 1.2 times the bankfull channel width. The bankfull width of Rock Creek at the crossing site is approximately 25-feet, thus a span of around 30-feet will be required. The road surface at the crossing site is only about 3 feet above the bankfull stream elevation, allowing little freeboard. As a result, the cover depth available to meet structural requirements of American Association of State Highway Transportation Officials standards for corrugated metal culverts is limited. Our preliminary assessment suggests that as a result of the limited freeboard, a pre-cast bottomless concrete box culvert or bridge will probably be required.

The cost of replacing the structure will depend not only on the type of structure used, but on future anticipated traffic volumes and ancillary safety features such as sidewalks and guardrails that may need to be incorporated into the design. At a minimum, replacement of the existing structure with an improved design that passes fish and has a road width and safety features comparable to what exists on site today is approximately $600,000. Actual costs may vary

substantially from this estimate and could be as high as $1,000,000. Project plans will also need to identify how flows and fish will be passed during construction.

Figure 10. Looking upstream at the Summit Landsburg Road crossing on Rock Creek, February 3, 2005 at a flow of 15 cfs.

If the culvert replacement project is undertaken, it should be done in close cooperation with city, county and state road and transportation departments. The likelihood of future road upgrades or needs in light of local growth projections and ranking on the City and/or County CIP list should be investigated prior to committing resources to specific design and construction approaches.

## 4.4 R12-1. LWD PLACEMENT IN REACH 12

A portion of Reach 12 currently consists of a uniform channel with a bed composed predominantly of sand, and scarce instream cover (Figure 11). Addition of individual pieces of LWD to this area would provide hiding cover for adult fish and increase the hydraulic complexity, causing local increases in flow velocity that could potentially enhance spawning habitat for sockeye and coho salmon by maintaining areas of cleaner gravel.

Figure 12 presents a plan and section view of LWD placement that could be implemented to enhance habitat in Reach 12. The high permeability soils of the upper Rock Creek watershed give rise to a flow regime that is fed predominantly by groundwater flow, thus peak flows tend to be lower and rise and fall gradually in comparison with the flashier flows of basins fed primarily by surface water runoff. As a result, LWD placed in Reach 12 is expected to remain relatively stable, and would not require extensive armoring. Logs could be stabilized by wedging them against trees on site, and strategic hand placement of several one to two-man boulders sized sufficiently to counteract drag and buoyancy forces. However, if placed LWD were to move during high flows it would likely deposit in the multi-thread section of channel located immediately downstream.

Figure 11. Looking upstream in Reach 12 of Rock Creek, at suggested location of LWD enhancement, February 3, 2005 at a flow of 15 cfs.

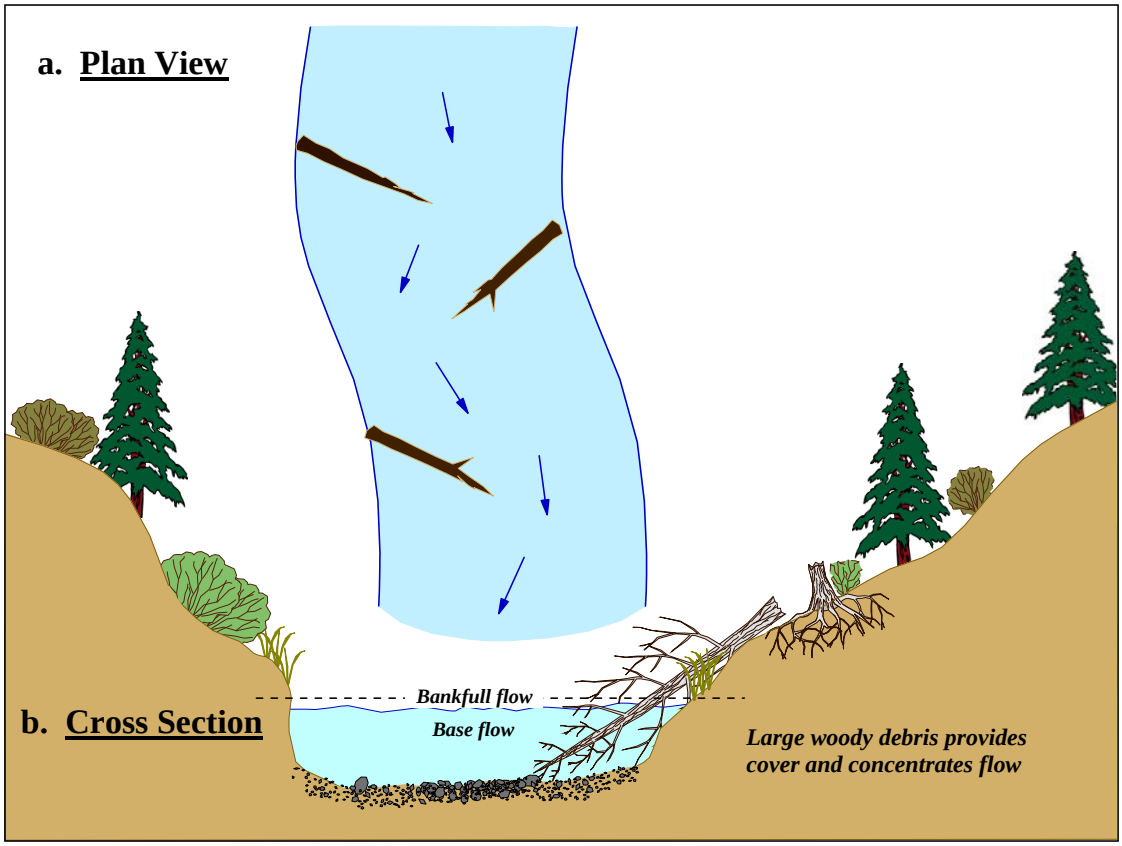



Figure 12. Section (a) and plan view (b) sketches of the suggested Rock Creek Reach 12 LWD enhancement.

Three recently recruited conifers that span the channel are currently available on site (Figure 11). These logs could be cut and re-oriented as depicted in Figure 12, using a come-along/pulley system, resulting in minimal site disturbance. The work would require an HPA, but could potentially be permitted using the streamlined Joint Aquatic Resource Permit Application (JARPA) process if the activity is part of an approved watershed restoration plan sponsored by the City of Kent (RCW 89.08). Total estimated cost, including development of final designs and permitting, is anticipated to be approximately $15,000.

## 4.5 R10-1. LWD PLACEMENT IN REACH 10

A portion of Reach 10 located immediately downstream of the footbridge currently consists of a uniform channel with a bed composed predominantly of sand, and scarce in-stream cover, similar to that identified in Reach 12. Addition of several individual pieces of LWD to this area would provide hiding cover for adult fish and increase the hydraulic complexity, causing local

increases in flow velocity that could potentially enhance spawning habitat for sockeye and coho salmon by maintaining areas of cleaner gravel. The same conceptual design approach described for Reach 12 could be implemented in Reach 10. No LWD was identified on-site at this location, thus LWD would have to be purchased or obtained from elsewhere on the watershed property. Importing LWD to the site could require minimal site clearing and post-construction re-planting.

Implementation of this project would require final design, and potentially clearing and grading plans and a revegetation plan. Permitting could again be potentially accomplished using the streamlined JARPA process. The total anticipated cost including design, permitting and purchase of logs would be approximately $15,000 to $25,000.

## 4.6 FENCING AROUND LOWER PORTION OF CITY OF KENT WATERSHED PROPERTY

An abundance of trash was observed in the stream channel of Reach 9 during the February 28th reconnaissance survey. The majority of the material appeared to be inert, but the possibility exists that materials which would cause substantial adverse impacts to water quality and fish could be introduced. Fencing the remaining watershed property would reduce, but not completely prevent this risk. Conducting periodic patrols and removing trash would also improve watershed conditions.

## 4.7 R2-1. ENHANCEMENT OF REACH 2 POND/WETLAND COMPLEX

The pond and wetland complex adjacent to the east bank of Rock Creek in Reach 2 just upstream of the SE 246th Street footbridge is currently connected to Rock Creek at all but the lowest flows, and thus functions to provide off-channel rearing habitat. However, pond substrate consists of a thick layer of organic muck that reduces rearing area and could contribute to anoxic conditions. Overhead canopy cover is currently sparse on the east and south sides, thus the pond is exposed to solar radiation that may elevate water temperatures in the summer.

Existing pond habitat could be improved by excavating the organic material to a depth of around 2-4 feet, constructing an island in the center of the pond that would support trees and shrubs and provide increased shade, and by placement of LWD in the excavated pond to provide hiding cover. Minor excavation of the pond inlet could be completed to provide access at all flow levels. Figures 13 and 14 show the existing pond and a conceptual design sketch of suggested reconfiguration.

Figure 13. Existing pond wetland complex adjacent to Reach 2, looking east from Rock Creek on February 3, 2005. Rock Creek flow of 15 cfs.

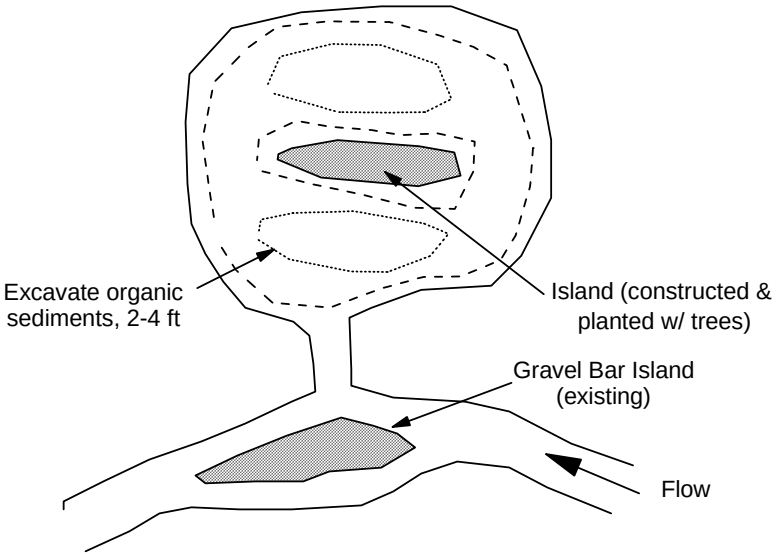



Figure 14. Conceptual plan view design sketch of the suggested reconfiguration of the pond and wetland complex associated with Reach 2 of lower Rock Creek.

A detailed topographic survey of the pond configuration, depth and inlet connectivity should be completed in support of project design to ensure that implementation of the project does not capture additional flow from Rock Creek during the summer. Monitoring of pond water surface levels, temperature and DO during the summer should also be conducted prior to final design and implementation of this project.

Access to the pond for excavation can be accomplished via SE 246th St and 244th Place SE. The existing pond is small enough that an excavator can likely reach much of the area to be excavated; however, some vegetation clearing and use of equipment in the wetland may be required. The pond is located on King County land and thus this project will require landowner support and consent.

Estimated design, construction and permitting costs for this project are approximately $15,000 to $25,000. This cost estimate assumes that the landowner supports implementation of the project and that acquisition of additional real estate and easements is not required. The pond may gradually refill with organic material over time, thus maintenance in the form of re-excavation of organic matter may be required in the future. Pond filling is anticipated to occur over multiple decades however, thus no major maintenance is anticipated over the term of the HCP. Minor maintenance to maintain inlet connectivity could be accomplished with hand tools when needed.

Enhancement of pond habitat will improve off-channel rearing habitat available to juvenile salmonids in Rock Creek. Given the proximity of this site to the Cedar River (425-ft travel distance), it is also possible that juvenile fish originating from the Cedar River could access the site, particularly during high flows. Off-channel habitats are preferred by coho salmon, but are also sometimes used by juvenile Chinook salmon in the nearby Green River (Jeanes and Hilgert 2000).

# 5. LITERATURE CITED

Burlingame, J. 2005. Personal communication. Conversation between Joan Burlingame, Friends of Rock Creek Valley and Sue Madsen, Paul DeVries. February 3, 2005.

Chinook Engineering. 2004. The Seattle Public Utilities Lake Youngs Aqueduct Culvert Crossing of Rock Creek Near Maple Valley, WA. Conceptual Alternative Report. Prepared for Seattle Public Utilities. November 19, 2004.

Friends of Rock Creek Valley. 2004. Rock Creek Valley Conservation Plan and Priorities. Friends of Rock Creek Valley. Maple Valley, Washington. 63 pp.

Jeanes, E.D., and P.J. Hilgert. 2000. Juvenile salmonid use of lateral stream habitats middle Green River, Washington. 1999 Data Report. Prepared for the U.S. Army Corps of Engineers, Seattle District, and City of Tacoma Public Utilities, Tacoma Water by R2 Resource Consultants, Inc. July 2000. ~200 pp.

Jones and Stokes. 1993. Wilderness Retreat/Wilderness 50 Stream Survey. Technical Appendix. April 6. (JSA 91-213). Bellevue, WA. Prepared for King County Department of Development and Environmental Services, Environmental Division, King County, Washington.

Pentec. 2001. Rock Creek Fish Habitat Survey. Consultant Report prepared for the City of Kent.

Washington Department of Fish and Wildlife (WDFW). 2003. Design of Road Culverts for Fish Passage. Washington Department of Fish and Wildlife, Olympia, Washington.

WRIA 8 Steering Committee. 2004. Draft Chinook Conservation Plan for WRIA 8. Public Review Draft available for download at http://dnr.metrokc.gov/wrias/8/chinook-conservation-plan.htm. November 2004.

*This page intentionally left blank.*

# APPENDIX J

## Analysis of Water Depths at PHABSIM Transects

*Prepared by:*

Alan Olson
Dudley Reiser

R2 Resource Consultants, Inc.
15250 NE 95th Street
Redmond, WA 98052

January 24, 2006

*This page intentionally left blank.*

# APPENDIX J

## Analysis of Water Depths at PHABSIM Transects

### Introduction

Water flow and depth during the fall and late summer are important issues for the Habitat Conservation Plan under preparation for the City of Kent's Clark Springs Water Supply located within the Rock Creek basin because low flows have the potential to limit the upstream passage of adult salmon. NOAA Fisheries and US Fish and Wildlife Service (Services) requested that an analysis of water depth under different flow conditions be conducted at transects utilized for the Physical Habitat Simulation (PHABSIM) methodology. The following reports the methods and results of the analysis, including a brief discussion.

In general, the main criterion for successful upstream passage at low flows is depth. Many minimum depth criteria can be found in the literature for salmonids, varying with species and investigation. Table 1 lists depth criteria from several studies. The majority of studies have focused on the design of fish ladders, culverts, spawning channels, and other man-made structures, emphasizing not only the conditions within the structure, but also at the entrance and exit (e.g., Chambers et al. 1955; Thompson 1970; Slatick 1970, Slatick 1975; Weaver et al. 1976; Evans and Johnston 1980; Bell 1991). Some studies have aimed at evaluating passages conditions in natural channels (e.g., Mosley 1982; Thompson 1972).

As can be seen from Table 1, various investigators have suggested different criteria for the minimum depth. It is useful to consider two principles when examining minimum depth criteria. First, Powers and Orsborn (1985b) emphasized that flow depth should be greater than body depth for the fish to make full use of its propulsive power. Second, Evans and Johnston (1980) emphasized that fish passage structures must be designed for the successful passage of all fish, not just the most fit. However, in stream systems, locations that do not meet depth criteria under natural conditions at a specified time do not necessarily result in a complete barrier to the upstream migration of fish. Depending on the actual depth of water and the length of stream containing shallow depths that must be traversed to reach the next deeper segment of stream, adult salmonids can successfully migrate upstream in water shallower than their body depth.

For the analysis of Rock Creek we concluded that optimal passage for Chinook salmon would generally occur at depths of 1.0 feet or more following the recommendations of Bell (1991) (Table 1).

Table 1. Depth criteria reported for salmonid upstream passage.

| Author(s) | Depth (ft) | Comments |
|---|---|---|
| Ziemer (cited in Orsborn and Powers, 1985b) | 0.5-1.0 | Weir design values for salmon and shad |
| Rizzo (cited in Orsborn and Powers, 1985b) | 1.0 | Weir design, unknown salmonids |
| Thompson (1970) | 1.0-1.25 | Weir design for salmon and steelhead |
| Thompson (1972) | | Minimum for: |
| | 0.8 | Chinook salmon |
| | 0.6 | Coho salmon, steelhead, and large trout |
| | 0.4 | Trout |
| Weaver et al. (1976) | | Minimum for coho and fall run Chinook salmon, and steelhead (weir passage): |
| | 1.0 | 3 foot high sill |
| | 2.0 | 4 foot high sill |
| Dane (1978) (cited in Orsborn and Powers, 1985b) | 0.75 | Culvert design minimum for Pacific salmon |
| Evans and Johnston (1980) | | Culvert design minimum for: |
| | 0.5 | Trout |
| | 1.0 | Salmon |
| Bell (1991) | | Minimum design values for: |
| | 0.5 | Trout |
| | 1.0 | Salmon |
| Powers and Orsborn (1985a) | 0.4 | Minimum chute depth for coho salmon (will not pass all fish) |

There are few studies on the minimum width over which a depth criterion should be applied. Thompson (1972) concluded that minimum depth criteria would be needed over a minimum of 10 percent of the channel width. Powers and Orsborn (1985a) observed that depths of 0.4 to 0.6 feet were adequate for coho and chum to pass through a chute 1.25 feet in width; however their study was designed to examine depth criteria rather than width. WDFW (2000) recommends a minimum orifice width of 1.5 feet for fish ladders in their draft fishway guidelines, but indicate that widths of 1.0 foot are occasionally used. WDFW (2000) also recommends a minimum bar separation width of 1.5 feet for trash racks to allow adequate fish passage. Taken together, one can conclude that applying the minimum depth criteria over a minimum 1.0 to 1.5 feet width of channel appears adequate for complete passage.

Within the WRIA 8 Draft Conservation Plan (WRIA 8 Steering Committee 2005), the results of the Ecosystem Diagnosis and Treatment (EDT) model suggested that under current conditions the availability of adult holding habitat in Rock Creek was a limiting factor relative to template conditions. The EDT model utilizes twelve environmental attributes (flow, embeddedness, 5 attributes related to the presence of different habitat types, riparian function, instream large woody debris, gradient, natural confinement, and hydromodification) to calculate 3 of the 10 survival factors (flow, habitat diversity, and key habitat) in its evaluation of adult holding habitat conditions (MBI 2003). While it is not possible to use the current analysis to directly evaluate the EDT results regarding adult holding habitat because the attributes to be evaluated are different, it is possible to utilize depth data to evaluate pool depths along the transects relative to depth criterion for holding pool habitat. The Washington Department of Natural Resources Watershed Assessment Manual (WADNR 1995) utilizes a minimum pool depth of 3.3 feet as a criterion for holding habitat.

## DEPTH ANALYSIS METHODS APPLIED TO ROCK CREEK

The PHABSIM analysis conducted in Rock Creek utilized 37 cross-sections measured at low, medium, and high flows. MCS Environmental collected data for 28 cross-sections and R2 Resource Consultants (R2) collected the data for the remaining nine cross-sections. The nine cross-sections collected by R2 are the focus of this analysis because they were in a format easily amenable to assessing water depth at different flows and they were generally representative of the other 28 cross-sections. Tables 2 and 3 list the nine cross-sections considered in this analysis.

Table 2. PHABSIM Site Information.

| Site | Approximate Site Location (RM) | Number of Transects | Field Collection Dates | | | Mean Measured Flow (cfs) | | |
|---|---|---|---|---|---|---|---|---|
| | | | Low | Medium | High | Low | Medium | High |
| A | 0.2 | 3 | 8/11/2004 | 5/5/2004 | 6/3/2004 | 2.7 | 5.6 | 10.7 |
| B | 0.6 | 3 | 8/11/2004 | 5/5/2004 | 6/3/2004 | 2.6 | 6.3 | 10.6 |
| C | 0.7 | 3 | 8/11/2004 | 5/5/2004 | 6/3/2004 | 2.8 | 6.3 | 10.9 |

Water velocity and depth are measured at each station along the cross-section (typically every 0.5 to 1.0 foot). Water surface elevation is measured at the channel edge and several locations across the cross-section. Elevations are measured relative to a local benchmark that was arbitrarily assigned an elevation of 100 feet. Hydraulic modeling using data collected at the measured flows allow the development of a water surface elevation versus flow relationship. A graphical example from Site A Transect 1 is provided in Figure 1.

Table 3. Transects utilized in the flow-depth analysis.

| Site | Transect | Habitat Type |
|---|---|---|
| A | 1 | Pool |
| A | 2 | Pool |
| A | 3 | Riffle |
| B | 1 | Riffle |
| B | 2 | Riffle |
| B | 3 | Pool |
| C | 1 | Pool |
| C | 2 | Pool |
| C | 3 | Riffle |

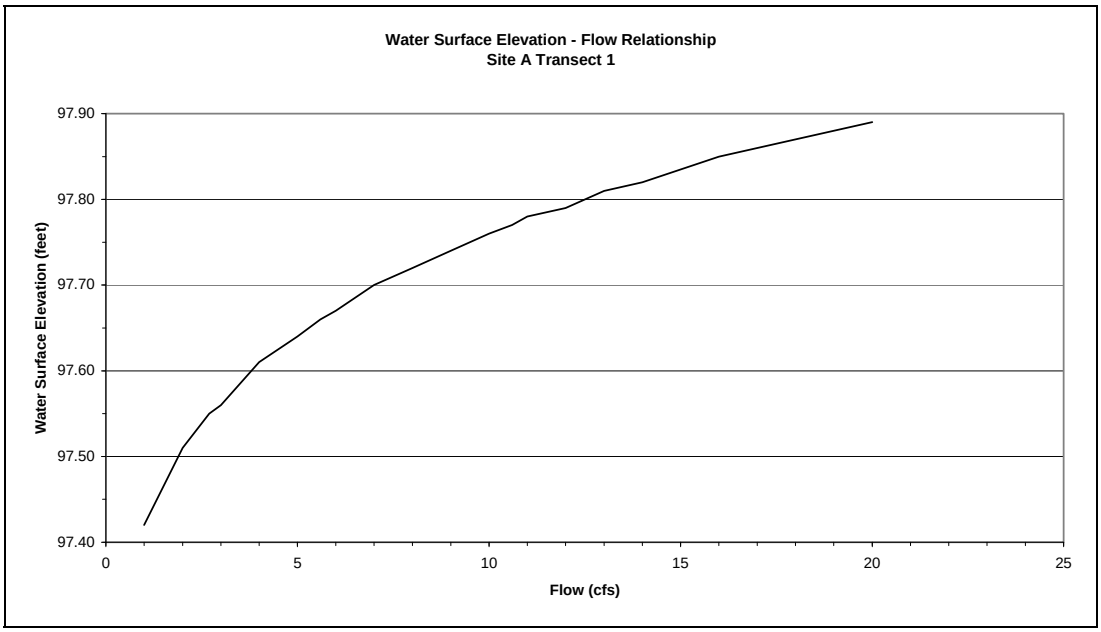



Figure 1. Example water surface elevation versus flow relationship.

Water depths at each station were calculated by subtracting the average elevation of the channel bottom from the water surface elevation at four selected flow levels representing a range of conditions from approximately baseline to natural (1.5 cfs, 3 cfs, 4 cfs, and 7 cfs). This range of flows was selected for illustrative purposes only as a means to document the sensitivity of depth across the transects to incremental changes in flow. The baseline condition was considered to be the water surface elevation at 1.5 cfs. Average channel elevations were used because of potential measurement error and small changes in the channels that may have occurred between surveys.

## RESULTS

Figures 2, 3, and 4 display the average cross-sectional profile and water surface elevations at three of the four flow levels (1.5, 3.0, and 7.0 cfs) for the nine transects. Table 4 summarizes the increase in water surface elevation at 3.0, 4.0, and 7.0 cfs relative to the baseline flow level. The mean increase in water surface elevation over the baseline (1.5 cfs) flow level was 1.1, 1.7, and 2.7 inches at the 3.0, 4.0, and 7.0 cfs flow levels. With the exception of Site B Transect 3 and Site C Transect 3, transects were all relatively close to the mean values.

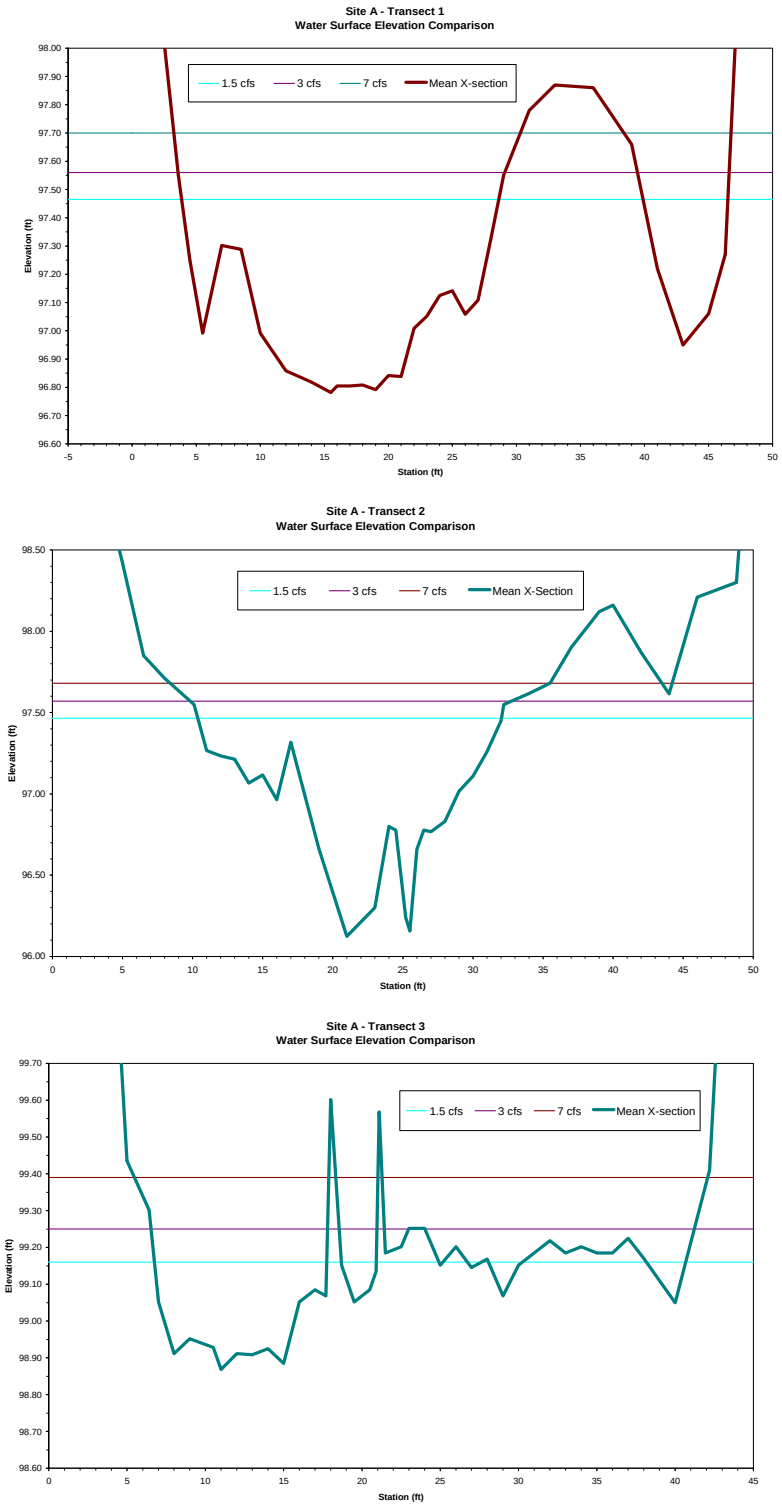



Figure 2. Transect cross-section profiles and water surface elevations for Site A.

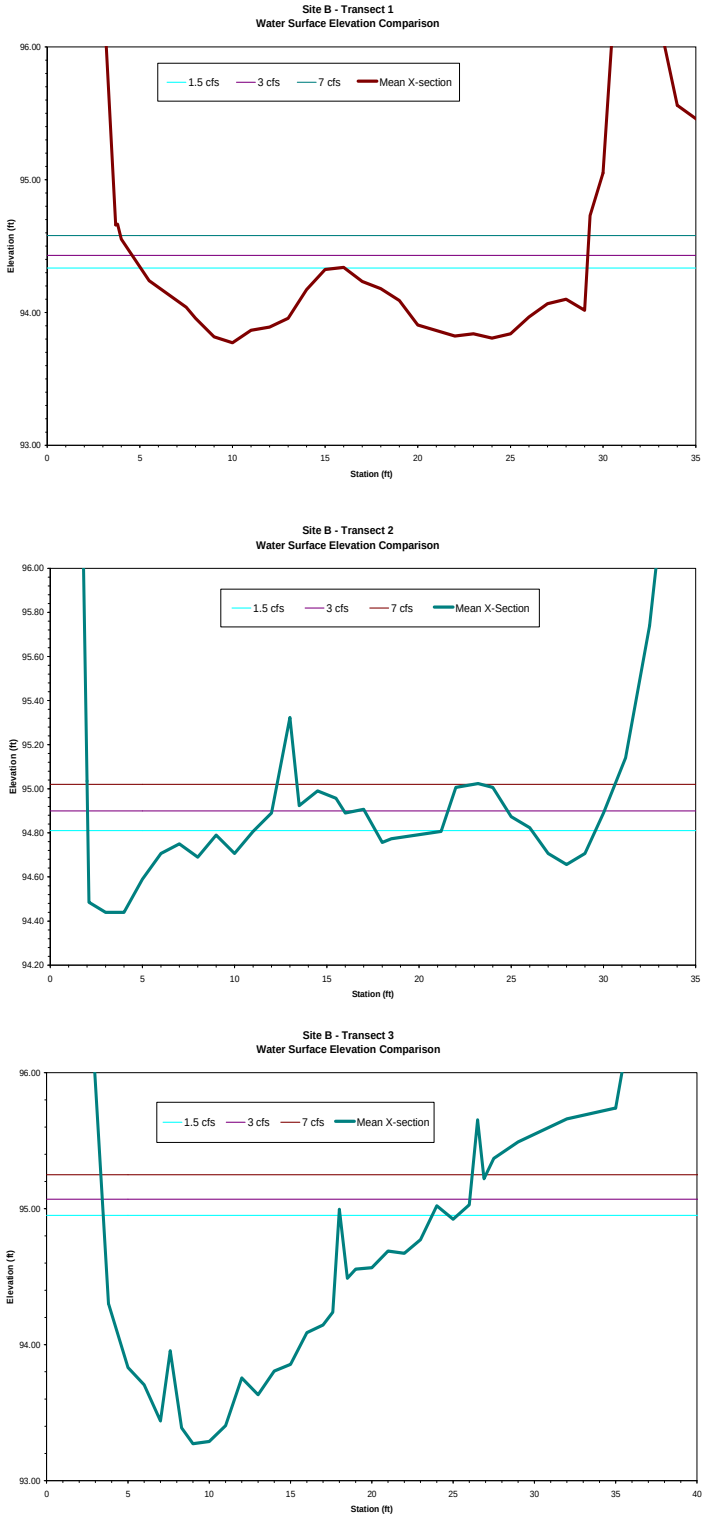



Figure 3. Transect cross-section profiles and water surface elevations for Site B.

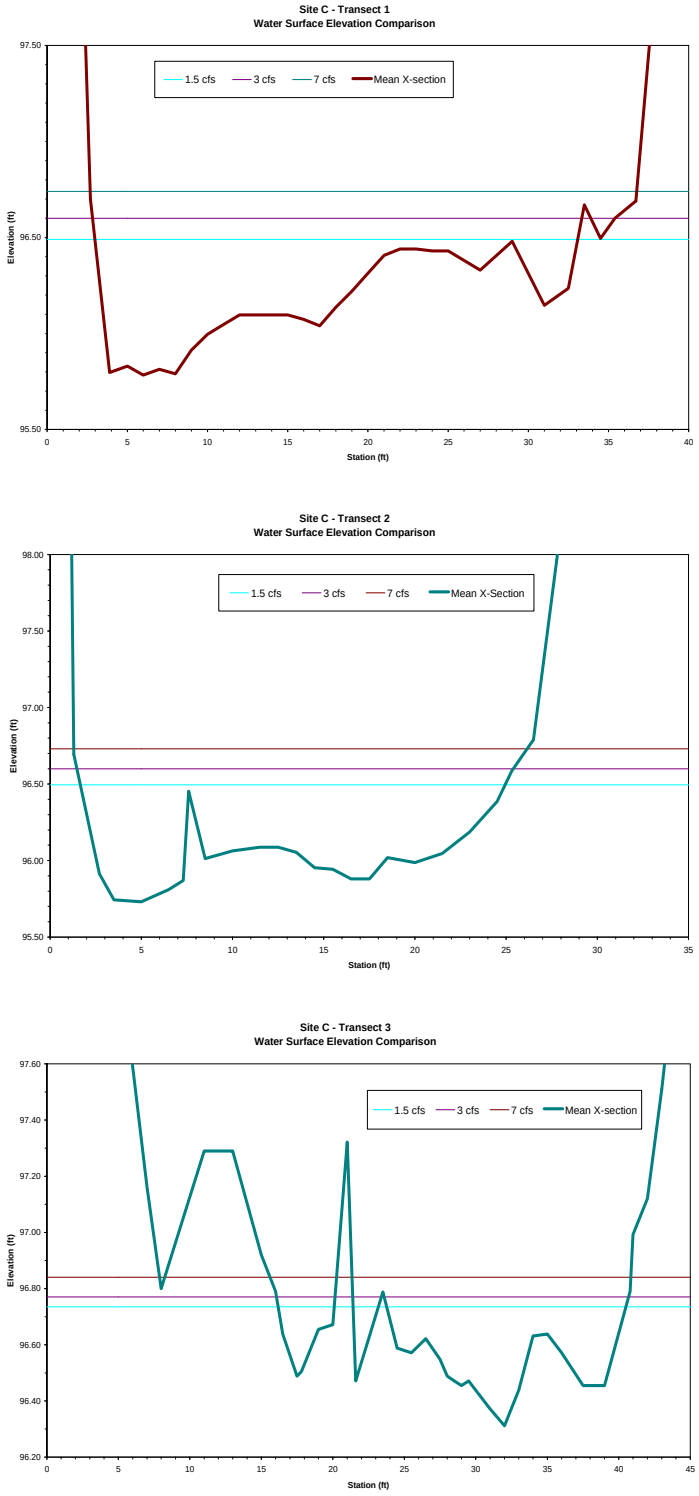



Figure 4. Transect cross-section profiles and water surface elevations for Site C.

Three depth statistics were also calculated for each transect at the four flow levels: maximum depth, mean depth, and mean depth of the primary channel (the portion of the channel with the greatest depth most likely to be utilized by an adult salmon) (Tables 5, 6, and 7). Examination of the maximum water depths (Table 5) indicates that in 6 of the 9 transects maximum depths are less than the 1.0 foot minimum depth criterion even at flows of 7.0 cfs. Consequently, Chinook passage based on water depth could be considered suboptimal at many stream locations in Rock Creek even under a no withdrawal flow scenario. Of the three transects that meet the 1.0-foot minimum criterion (Site A Transect 2, Site B Transect 3, and Site C Transect 2), two would also meet the criterion at the 1.5 cfs flow level.

It should be noted that during the previous three years of spawning surveys conducted by the City of Kent, flows during the fall spawning period have been voluntarily maintained at a minimum flow of 3.0 cfs. While few Chinook salmon have been observed in the stream during these years, substantial numbers of sockeye and coho salmon appear to migrate to the upper reaches without any apparent passage delay.

Regarding the availability of adult holding habitat, all of the transects located in pools were considerably shallower than the 3.3 feet criterion in WDNR (1995) under the 7.0 cfs, or lower, flow scenarios. The deepest pool evaluated, Site B Transect 3, was a maximum of 23.7 inches deep under the 7.0 cfs flow scenario. Flows of slightly over 50 cfs would be required to result in a 3.3-feet deep pool at this location. Habitat mapping suggested this pool was fairly representative of pools found in Rock Creek; about 31 percent of the pools (ten pools) had a greater residual depth (greater than 1.6 feet) over the 2.75 miles of stream surveyed, and the deepest pool measured during the habitat survey had a residual depth of 2.5 feet (R2 Resource Consultants 2004, unpublished data). The analysis confirms the EDT model result that pool habitat in Rock Creek is sub-optimal for Chinook adult holding habitat under current conditions. However, it also suggests that adult holding habitat would be sub-optimal under natural flow conditions and not substantially better than current conditions. Given the size and length of Rock Creek, plus its proximity to the Cedar River where deep pools are more likely to be available, it seems reasonable that adult Chinook salmon would utilize the Cedar River for holding habitat until ready for spawning in tributaries.

Table 4. Summary of water surface elevation (WSE) changes over baseline at three flows.

| | | Change (increase) in WSE (inches) over baseline | | | |
|---|---|---|---|---|---|
| **Site** | **Transect** | **1.5 cfs WSE (ft)** | **3.0 cfs** | **4.0 cfs** | **7.0 cfs** |
| A | 1 | 97.465 | 1.1 | 1.7 | 2.8 |
| | 2 | 97.465 | 1.3 | 1.7 | 2.6 |
| | 3 | 99.160 | 1.1 | 1.6 | 2.8 |
| B | 1 | 94.335 | 1.1 | 1.7 | 2.9 |
| | 2 | 94.810 | 1.1 | 1.6 | 2.5 |
| | 3 | 94.950 | 1.4 | 2.2 | 3.6 |
| C | 1 | 96.490 | 1.3 | 1.8 | 3.0 |
| | 2 | 96.495 | 1.3 | 1.9 | 2.8 |
| | 3 | 96.735 | 0.4 | 0.8 | 1.3 |
| | Minimum | | 0.4 | 0.8 | 1.3 |
| | Maximum | | 1.4 | 2.2 | 3.6 |
| | Mean | | 1.1 | 1.7 | 2.7 |

Table 5. Summary of maximum water depth at four flows.

| | | Maximum Depth (inches) | | | |
|---|---|---|---|---|---|
| **Site** | **Transect** | **1.5 cfs (Baseline)** | **3.0 cfs** | **4.0 cfs** | **7.0 cfs** |
| A | 1 | 8.2 | 9.3 | 9.9 | 11.0 |
| | 2 | 16.1 | 17.4 | 17.8 | 18.7 |
| | 3 | 3.5 | 4.6 | 5.1 | 6.3 |
| B | 1 | 6.7 | 7.9 | 8.5 | 9.7 |
| | 2 | 4.4 | 5.5 | 6.0 | 7.0 |
| | 3 | 20.1 | 21.6 | 22.3 | 23.7 |
| C | 1 | 8.5 | 9.8 | 10.3 | 11.5 |
| | 2 | 9.2 | 10.4 | 11.0 | 12.0 |
| | 3 | 5.1 | 5.5 | 5.9 | 6.3 |
| | Minimum | 3.5 | 4.6 | 5.1 | 6.3 |
| | Maximum | 20.1 | 21.6 | 22.3 | 23.7 |
| | Mean | 9.10 | 10.22 | 10.76 | 11.80 |

Table 6. Summary of mean water depth at four flows.

| | | Mean Depth (inches) | | | |
|---|---|---|---|---|---|
| **Site** | **Transect** | **1.5 cfs (Baseline)** | **3.0 cfs** | **4.0 cfs** | **7.0 cfs** |
| A | 1 | 5.3 | 6.5 | 7.1 | 8.2 |
| | 2 | 7.2 | 8.4 | 8.9 | 9.7 |
| | 3 | 1.6 | 2.7 | 3.2 | 4.4 |
| B | 1 | 4.0 | 5.1 | 5.7 | 6.9 |
| | 2 | 1.6 | 2.7 | 3.2 | 4.1 |
| | 3 | 11.0 | 12.4 | 13.2 | 14.6 |
| C | 1 | 4.3 | 5.6 | 6.1 | 7.3 |
| | 2 | 5.9 | 7.1 | 7.7 | 8.7 |
| | 3 | 2.5 | 3.0 | 3.3 | 3.8 |
| | Minimum | 1.6 | 2.7 | 3.2 | 3.8 |
| | Maximum | 11.0 | 12.4 | 13.2 | 14.6 |
| | Mean | 4.82 | 5.95 | 6.48 | 7.52 |

Table 7. Summary of mean water depth of the primary channel at four flows.

| | | Mean Depth (inches) of Primary Channel) | | | |
|---|---|---|---|---|---|
| **Site** | **Transect** | **1.5 cfs (Baseline)** | **3.0 cfs** | **4.0 cfs** | **7.0 cfs** |
| A | 1 | 5.9 | 7.1 | 7.7 | 8.8 |
| | 2 | 8.4 | 9.7 | 10.1 | 11.0 |
| | 3 | 2.4 | 3.5 | 3.9 | 5.1 |
| B | 1 | 3.8 | 5.0 | 5.6 | 6.8 |
| | 2 | 2.9 | 4.0 | 4.5 | 5.4 |
| | 3 | 14.3 | 15.8 | 16.5 | 17.9 |
| C | 1 | 5.3 | 6.6 | 7.1 | 8.3 |
| | 2 | 5.9 | 7.1 | 7.7 | 8.7 |
| | 3 | 2.8 | 3.2 | 3.6 | 4.0 |
| | Minimum | 2.4 | 3.2 | 3.6 | 4.0 |
| | Maximum | 14.3 | 15.8 | 16.5 | 17.9 |
| | Mean | 5.74 | 6.87 | 7.40 | 8.44 |

Table 8. Water surface elevation (WSE) versus flow relationship, WSE at four flows, and water depth at three transects located within Site A.

| | Site A | | |
|---|---|---|---|
| | **TR-1** | **TR-2** | **TR-3** |
| Q (cfs) | Calibrated WSE (ft) | Calibrated WSE (ft) | Calibrated WSE (ft) |
| 1 | 97.42 | 97.42 | 99.12 |
| 2 | 97.51 | 97.51 | 99.20 |
| 2.7 | 97.55 | 97.55 | 99.24 |
| 3 | 97.56 | 97.57 | 99.25 |
| 4 | 97.61 | 97.61 | 99.29 |
| 5 | 97.64 | 97.65 | 99.33 |
| 5.6 | 97.66 | 97.67 | 99.35 |
| 6 | 97.67 | 97.68 | 99.36 |
| 7 | 97.7 | 97.71 | 99.39 |
| 8 | 97.72 | 97.73 | 99.42 |
| 9 | 97.74 | 97.76 | 99.44 |
| 10 | 97.76 | 97.78 | 99.46 |
| 10.6 | 97.77 | 97.79 | 99.48 |
| 11 | 97.78 | 97.79 | 99.49 |
| 12 | 97.79 | 97.81 | 99.51 |
| 13 | 97.81 | 97.83 | 99.52 |

| | Site A | | | |
|---|---|---|---|---|
| | **Transect 1** | | | |
| | Baseline | | | |
| | Flow = 1.5 | Flow = 3 | Flow = 4 | Flow = 7 |
| Station | Water Surface Elevation (ft) | | | |
| -10 | 97.465 | 97.56 | 97.61 | 97.7 |
| 0 | 97.465 | 97.56 | 97.61 | 97.7 |
| 50 | 97.465 | 97.56 | 97.61 | 97.7 |
| | Change in WSE (inches) from Baseline | | | |
| | | 1.1 | 1.7 | 2.8 |
| Max Depth (inches) | 8.2 | 9.3 | 9.9 | 11.0 |
| Mean Depth (inches) | 5.3 | 6.5 | 7.1 | 8.2 |
| Mean Depth (inches) of primary channel (Station 8.5 to 28, 46.7% of total channel width at Baseline flow) | 5.9 | 7.1 | 7.7 | 8.8 |

| | | | | |
|---|---|---|---|---|
| | **Transect 2** | | | |
| | Baseline | | | |
| | Flow = 1.5 | Flow = 3 | Flow = 4 | Flow = 7 |
| Station | Water Surface Elevation (ft) | | | |
| -10 | 97.465 | 97.57 | 97.61 | 97.68 |
| 0 | 97.465 | 97.57 | 97.61 | 97.68 |
| 50 | 97.465 | 97.57 | 97.61 | 97.68 |

Table 8. Water surface elevation (WSE) versus flow relationship, WSE at four flows, and water depth at three transects located within Site A.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 14 | 97.82 | 97.84 | 99.54 | | Change in WSE (inches) from Baseline | | | |
| 16 | 97.85 | 97.87 | 99.58 | | | 1.3 | 1.7 | 2.6 |
| 18 | 97.87 | 97.89 | 99.61 | Max Depth (inches) | 16.1 | 17.4 | 17.8 | 18.7 |
| 20 | 97.89 | 97.92 | 99.64 | Mean Depth (inches) | 7.2 | 8.4 | 8.9 | 9.7 |
| | | | | Mean Depth (inches) of primary channel (Station 17 to 32.0, 68.2% of total channel width at Baseline flow) | 8.4 | 9.7 | 10.1 | 11.0 |
| | | | | | **Transect 3** | | | |
| | | | | | Baseline | | | |
| | | | | | Flow = 1.5 | Flow = 3 | Flow = 4 | Flow = 7 |
| | | | | Station | Water Surface Elevation (ft) | | | |
| | | | | -10 | 99.160 | 99.250 | 99.290 | 99.390 |
| | | | | 0 | 99.160 | 99.250 | 99.290 | 99.390 |
| | | | | 50 | 99.160 | 99.250 | 99.290 | 99.390 |
| | | | | | Change in WSE (inches) from Baseline | | | |
| | | | | | | 1.1 | 1.6 | 2.8 |
| | | | | Max Depth (inches) | 3.5 | 4.6 | 5.1 | 6.3 |
| | | | | Mean Depth (inches) | 1.6 | 2.7 | 3.2 | 4.4 |
| | | | | Mean Depth (inches) of primary channel (Station 7 to 17.7, 32.4% of total channel width at Baseline flow) | 2.4 | 3.5 | 3.9 | 5.1 |

Table 9. Water surface elevation (WSE) versus flow relationship, WSE at four flows, and water depth at three transects located within Site B.

| | Site B | | | | Site B | | | |
|---|---|---|---|---|---|---|---|---|
| | TR-1 | TR-2 | TR-3 | | Transect 1 | | | |
| | Calibrated | Calibrated | Calibrated | | Baseline | | | |
| Q | WSE | WSE | WSE | | Flow = 1.5 | Flow = 3 | Flow = 4 | Flow = 7 |
| (cfs) | (ft) | (ft) | (ft) | Station | Water Surface Elevation (ft) | | | |
| 1 | 94.29 | 94.77 | 94.90 | 0 | 94.335 | 94.43 | 94.48 | 94.58 |
| 2 | 94.38 | 94.85 | 95.00 | 5 | 94.335 | 94.43 | 94.48 | 94.58 |
| 2.6 | 94.41 | 94.88 | 95.05 | 40 | 94.335 | 94.43 | 94.48 | 94.58 |
| 3 | 94.43 | 94.90 | 95.07 | | Change in WSE (inches) from Baseline | | | |
| 4 | 94.48 | 94.94 | 95.13 | | | 1.1 | 1.7 | 2.9 |
| 5 | 94.52 | 94.98 | 95.17 | Max Depth (inches) | 6.7 | 7.9 | 8.5 | 9.7 |
| 6 | 94.55 | 95.01 | 95.21 | Mean Depth (inches) | 4.0 | 5.1 | 5.7 | 6.9 |
| 6.3 | 94.56 | 95.02 | 95.22 | Mean Depth (inches) of primary channel (Station 5.5 to 15, 46.9% of total channel width at Baseline flow) | 3.8 | 5.0 | 5.6 | 6.8 |
| 7 | 94.58 | 95.04 | 95.25 | | | | | |
| 8 | 94.60 | 95.06 | 95.28 | | Transect 2 | | | |
| 9 | 94.63 | 95.09 | 95.31 | | Baseline | | | |
| 10 | 94.65 | 95.11 | 95.34 | | Flow = 1.5 | Flow = 3 | Flow = 4 | Flow = 7 |
| 10.6 | 94.66 | 95.12 | 95.35 | Station | Water Surface Elevation (ft) | | | |
| 11 | 94.67 | 95.13 | 95.36 | 0 | 94.810 | 94.9 | 94.94 | 95.02 |
| 12 | 94.69 | 95.15 | 95.39 | 5 | 94.81 | 94.9 | 94.94 | 95.02 |
| 13 | 94.70 | 95.17 | 95.41 | 50 | 94.81 | 94.9 | 94.94 | 95.02 |

Table 9. Water surface elevation (WSE) versus flow relationship, WSE at four flows, and water depth at three transects located within Site B.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 14 | 94.72 | 95.18 | 95.43 | | Change in WSE (inches) from Baseline | | | |
| 15 | 94.73 | 95.20 | 95.45 | | | 1.1 | 1.6 | 2.5 |
| 16 | 94.75 | 95.22 | 95.47 | Max Depth (inches) | 4.4 | 17.2 | 17.7 | 18.6 |
| 18 | 94.78 | 95.25 | 95.51 | Mean Depth (inches) | 1.6 | 8.2 | 8.7 | 9.7 |
| 20 | 94.80 | 95.27 | 95.54 | Mean Depth (inches) of primary channel (Station 2.1 to 7.0, 18.2% of total channel width at Baseline flow) | 2.9 | 9.5 | 10.0 | 10.9 |
| 22 | 94.82 | 95.30 | 95.57 | | | | | |
| 24 | 94.85 | 95.32 | 95.60 | | **Transect 3** | | | |
| 26 | 94.87 | 95.35 | 95.63 | | Baseline | | | |
| 28 | 94.88 | 95.37 | 95.65 | | Flow = 1.5 | Flow = 3 | Flow = 4 | Flow = 7 |
| 30 | 94.90 | 95.39 | 95.68 | Station | Water Surface Elevation (ft) | | | |
| 35 | 94.94 | 95.44 | 95.74 | 0 | 94.950 | 95.070 | 95.130 | 95.250 |
| 40 | 94.98 | 95.48 | 95.79 | 5 | 94.950 | 95.070 | 95.130 | 95.250 |
| 45 | 95.02 | 95.52 | 95.84 | 50 | 94.950 | 95.070 | 95.130 | 95.250 |
| 50 | 95.05 | 95.56 | 95.88 | | Change in WSE (inches) from Baseline | | | |
| | | | | | | 1.4 | 2.2 | 3.6 |
| | | | | Max Depth (inches) | 20.1 | 21.6 | 22.3 | 23.7 |
| | | | | Mean Depth (inches) | 11.0 | 12.4 | 13.2 | 14.6 |
| | | | | Mean Depth (inches) of primary channel (Station 3.8 to 17.6, 65.1% of total channel width at Baseline flow) | 14.3 | 15.8 | 16.5 | 17.9 |

Table 10. Water surface elevation (WSE) versus flow relationship, WSE at four flows, and water depth at three transects located within Site C.

| | Site C | | | | Site C | | | |
|---|---|---|---|---|---|---|---|---|
| | **TR-1** | **TR-2** | **TR-3** | | **Transect 1** | | | |
| | Calibrated | Calibrated | Calibrated | | Baseline | | | |
| Q | WSE | WSE | WSE | | Flow = 1.5 | Flow = 3 | Flow = 4 | Flow = 7 |
| (cfs) | (ft) | (ft) | (ft) | Station | Water Surface Elevation (ft) | | | |
| 1 | 96.44 | 96.45 | 96.72 | 0 | 96.49 | 96.6 | 96.64 | 96.74 |
| 2 | 96.54 | 96.54 | 96.75 | 5 | 96.49 | 96.6 | 96.64 | 96.74 |
| 2.6 | 96.59 | 96.59 | 96.77 | 40 | 96.49 | 96.6 | 96.64 | 96.74 |
| 3 | 96.60 | 96.60 | 96.77 | | Change in WSE (inches) from Baseline | | | |
| 4 | 96.64 | 96.65 | 96.80 | | | 1.3 | 1.8 | 3.0 |
| 5 | 96.68 | 96.69 | 96.80 | Max Depth (inches) | 8.5 | 9.8 | 10.3 | 11.5 |
| 6 | 96.71 | 96.72 | 96.82 | Mean Depth (inches) | 4.3 | 5.6 | 6.1 | 7.3 |
| 6.3 | 96.72 | 96.73 | 96.83 | Mean Depth (inches) of primary channel (Station 3.9 to 22.0, 63.3% of total channel width at Baseline flow) | 5.3 | 6.6 | 7.1 | 8.3 |
| 7 | 96.74 | 96.75 | 96.84 | | | | | |
| 8 | 96.77 | 96.77 | 96.86 | | **Transect 2** | | | |
| 9 | 96.79 | 96.79 | 96.88 | | Baseline | | | |
| 10 | 96.81 | 96.81 | 96.90 | | Flow = 1.5 | Flow = 3 | Flow = 4 | Flow = 7 |
| 10.6 | 96.83 | 96.83 | 96.91 | Station | Water Surface Elevation (ft) | | | |
| 11 | 96.85 | 96.85 | 96.93 | 0 | 96.495 | 96.6 | 96.65 | 96.73 |
| 12 | 96.88 | 96.88 | 96.96 | 5 | 96.495 | 96.6 | 96.65 | 96.73 |

Table 10. Water surface elevation (WSE) versus flow relationship, WSE at four flows, and water depth at three transects located within Site C.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 13 | 96.89 | 96.90 | 96.97 | 50 | 96.495 | 96.6 | 96.65 | 96.73 |
| 14 | 96.91 | 96.91 | 96.99 | | Change in WSE (inches) from Baseline | | | |
| 15 | 96.92 | 96.92 | 97.00 | | | 1.3 | 1.9 | 2.8 |
| 16 | 96.93 | 96.94 | 97.01 | Max Depth (inches) | 9.2 | 10.4 | 11.0 | 12.0 |
| 18 | 96.95 | 96.95 | 97.02 | Mean Depth (inches) | 5.9 | 7.1 | 7.7 | 8.7 |
| 20 | 96.96 | 96.96 | 97.04 | Mean Depth (inches) of primary channel (Station 2.7 to 24.5, 100% of total channel width at Baseline flow) | 5.9 | 7.1 | 7.7 | 8.7 |
| 22 | 96.98 | 96.98 | 97.06 | | | | | |
| 24 | 97.00 | 97.00 | 97.08 | | **Transect 3** | | | |
| 26 | 97.02 | 97.02 | 97.10 | | Baseline | | | |
| 28 | 97.04 | 97.04 | 97.12 | | Flow = 1.5 | Flow = 3 | Flow = 4 | Flow = 7 |
| 30 | 97.05 | 97.06 | 97.13 | Station | Water Surface Elevation (ft) | | | |
| 35 | 97.09 | 97.09 | 97.17 | 0 | 96.735 | 96.770 | 96.800 | 96.840 |
| 40 | 97.13 | 97.13 | 97.21 | 5 | 96.735 | 96.770 | 96.800 | 96.840 |
| 45 | 97.15 | 97.16 | 97.24 | 50 | 96.735 | 96.770 | 96.800 | 96.840 |
| 50 | 97.18 | 97.19 | 97.27 | | Change in WSE (inches) from Baseline | | | |
| | | | | | | 0.4 | 0.8 | 1.3 |
| | | | | Max Depth (inches) | 5.1 | 5.5 | 5.9 | 6.3 |
| | | | | Mean Depth (inches) | 2.5 | 3.0 | 3.3 | 3.8 |
| | | | | Mean Depth (inches) of primary channel (Station 24.5 to 41.0, 67.3% of total channel width at Baseline flow) | 2.8 | 3.2 | 3.6 | 4.0 |

## References

Bell, M.C. 1991. Fisheries handbook of engineering requirements and biological criteria. U.S. Army Corps of Engineers, Office of the Chief of Engineers.

Chambers, J.S., G.H. Allen, and R.T. Pressey. 1955. Research relating to study of spawning grounds in natural areas. Wash. Dept. Fish. Annual Report to the Army Corps of Engineers. 175 pp.

Evans, W.A. and B. Johnston. 1980. Fish migration and fish passage. USDA Forest Service, EM-7100-12, Washington D.C. 63 pp. plus appendices.

MBI. Mobrand Biometrics, Inc. 2003. Information Structure of EDT. Mobrand Biometrics, Inc.

Mosley, M.P. 1982. Critical depths for passage in braided rivers, Canterbury, New Zealand. New Zealand J. Mar. Freshwat. Res. 16: 351-357.

Orsborn, J.F. and P.D. Powers. 1985. Fishways -- An assessment of their Development and Design. Prepared by Albrook Hydraulics Laboratory, Washington State University for Bonneville Power Administration, Portland, Oregon. 161 pp.??

Powers, P.D. and J.F. Orsborn. 1985. An investigation of the physical and biological conditions affecting fish passage success at culverts and waterfalls. Part IV: Analysis of Barriers to Upstream Fish Migration - Final Report. Prepared by Albrook Hydraulics Laboratory, Washington State University for Bonneville Power Administration, Portland, Oregon. 120 pp.

Slatick, E. 1975. Laboratory evaluation of a Denil-type steepass fishway with various entrance and exit conditions for passage of adult salmonids and American shad. Mar. Fish. Rev. 37(9): 17-26.

Slatick, E. 1970. Passage of adult salmon and trout through pipes. Special Scientific Report: Fisheries No. 592, Washington, D.C.

Thompson, C.S. 1970. Effect of flow on performance and behavior of chinook salmon in fishways. U.S.F.W.S., Special Scientific Report: Fisheries No. 601, Washington D.C.

Thompson, K.E. 1972. Determining stream flows for fish life. Proceedings of the instream flow requirements workshop, Pacific Northwest River Basins Commission, Portland, Oregon: 31-50.

Washington State DNR. 1995. Standard Methodology for Conducting Watershed Analysis. Version 3.0. Washington State Department of Natural Resouces. Forest Practices Division.

WDFW. Washington Department of Fish and Wildlife. 2000. Draft Fishway Guidelines for Washington State. Washington Department of Fish and Wildlife, Olympia, Washington. 57 pp.

Weaver, C.R., C.S. Thompson, and E. Slatick. 1976. Fish passage research at the fisheries engineering research laboratory, May 1965 to September 1970. U.S. Army Corps of Engineers, North Pacific Division, Forth Progress Report on Fisheries Engineering Research Program 1966-1972, Report No. 32, Portland, Oregon.

WRIA 8 Steering Committee. 2005. Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Chinook Salmon Conservation Plan. WRIA 8 Steering Committee.

*This page intentionally left blank.*

# APPENDIX K

## City of Kent Construction Standards

(Compact Disc Insert)

*This page intentionally left blank.*

# APPENDIX L

## Beaver Dam Management
## Hydraulic Project Approval

*This page intentionally left blank.*

Washington Department of FISH and WILDLIFE

# HYDRAULIC PROJECT APPROVAL

RCW 77.55.021 - Appeal pursuant to Chapter 34.05 RCW

North Puget Sound
16018 Mill Creek Boulevard
Mill Creek, WA 98012-1296
(425) 775-1311

Issue Date: October 10, 2006
Project Expiration Date: October 09, 2011

Control Number: 107070-1
FPA/Public Notice #: N/A

| PERMITTEE | AUTHORIZED AGENT OR CONTRACTOR |
|---|---|
| Kent City Of Public Works Department<br>ATTENTION: Kelly Peterson<br>400 West Gowe St.<br>Kent, WA 98032<br>253-856-5547 | |

Project Name: Manage Beaver Dams

Project Description: Remove or modify beaver dams at the Clark Springs facility on Rock Creek upstream of SE Kent-Kangley Road

## PROVISIONS

1. Management of beaver dams below the ordinary high water line (OHWL) may begin immediately and may occur until October 9, 2011.

2. Work shall be accomplished as discussed with and approved by the Washington Department of Fish and Wildlife (WDFW) Area Habitat Biologist (AHB). This includes lowering the elevation of an existing upstream beaver dam to no less than two inches above the base flow elevation and the removal of a notch no greater than three feet wide and no lower than six inches above the base flow elevation in a blown out downstream beaver dam. This Hydraulic Project Approval (HPA) may be subsequently modified to address future beaver dam issues at the site.

3. Woody material which is embedded in the streambanks or streambed shall not be removed.

4. Dam removal shall occur in a manner to release water at a slow, controlled rate to prevent downstream erosion and sedimentation.

5. Removed beaver dam materials shall be disposed of so they will not be available for re-use by beavers.

6. Disturbance of the streambed and banks and their associated vegetation shall be limited to that necessary to perform the project. Affected streambed and bank areas shall be restored to preproject or improved habitat configuration. Prior to December 31 of the year of project performance, the disturbed areas of vegetation shall be revegetated with native or other woody species approved by the WDFW Area Habitat Biologist (AHB) listed below. Vegetative cuttings shall be planted at a maximum interval of three feet (on center). Plantings shall be maintained as necessary for three years to ensure 80 percent or greater survival of each species or a contingency species approved by the AHB.

7. If it is necessary to use equipment for this activity, the equipment shall be free of external petroleum-based products while working around the stream. Accumulation of soils or debris shall be removed from the drive mechanisms (wheels, tires, tracks, etc.) and undercarriage of equipment prior to its working below the OHWL. Equipment shall be checked daily for leaks and any necessary repairs shall be completed prior to commencing work activities along the stream.

8. If at any time, as a result of project activities, fish are observed in distress, a fish kill occurs, or water quality problems develop (including equipment leaks or spills), immediate notification shall be made to the Washington Emergency Management Division at 1-800-258-5990, and to the AHB.

9. Erosion control methods shall be used to prevent silt-laden water from entering the stream. These may include, but are not limited to, straw bales, filter fabric, and/or immediate mulching of exposed areas.

10. Extreme care shall be taken to ensure that no petroleum products, hydraulic fluid, fresh cement, sediments, sediment-laden water, chemicals, or any other toxic or deleterious materials are allowed to enter or leach into the stream.

## PROJECT LOCATIONS

Location #1 Manage Beaver Dams

| WORK START: October 10, 2006 | | | | | WORK END: October 09, 2011 | |
|---|---|---|---|---|---|---|
| WRIA: 08.0338 | Waterbody: Rock Creek | | | | Tributary to: Cedar River | |
| 1/4 SEC: SW 1/4 | Section: 26 | Township: 22 N | Range: 06 E | Latitude: N 47.36137 | Longitude: W 122.00831 | County: King |
| Location #1 Driving Directions | | | | | | |

## NOTES

## APPLY TO ALL HYDRAULIC PROJECT APPROVALS

This Hydraulic Project Approval pertains only to those requirements of the Washington State Hydraulic Code, specifically Chapter 77.55 RCW (formerly RCW 77.20). Additional authorization from other public agencies may be necessary for this project. The person(s) to whom this Hydraulic Project Approval is issued is responsible for applying for and obtaining any additional authorization from other public agencies (local, state and/or federal) that may be necessary for this project.

This Hydraulic Project Approval shall be available on the job site at all times and all its provisions followed by the person(s) to whom this Hydraulic Project Approval is issued and operator(s) performing the work.

This Hydraulic Project Approval does not authorize trespass.

North Puget Sound
16018 Mill Creek Boulevard
Mill Creek, WA 98012-1296
(425) 775-1311

Issue Date: October 10, 2006 | Control Number: 107070-1

Project Expiration Date: October 09, 2011 | FPA/Public Notice #: N/A

---

The person(s) to whom this Hydraulic Project Approval is issued and operator(s) performing the work may be held liable for any loss or damage to fish life or fish habitat that results from failure to comply with the provisions of this Hydraulic Project Approval.

Failure to comply with the provisions of this Hydraulic Project Approval could result in a civil penalty of up to one hundred dollars per day and/or a gross misdemeanor charge, possibly punishable by fine and/or imprisonment.

All Hydraulic Project Approvals issued pursuant to RCW 77.55.021 (EXCEPT agricultural irrigation, stock watering or bank stabilization projects) or 77.55.141 are subject to additional restrictions, conditions or revocation if the Department of Fish and Wildlife determines that new biological or physical information indicates the need for such action. The person(s) to whom this Hydraulic Project Approval is issued has the right pursuant to Chapter 34.04 RCW to appeal such decisions. All agricultural irrigation, stock watering or bank stabilization Hydraulic Project Approvals issued pursuant to RCW 77.55.021 may be modified by the Department of Fish and Wildlife due to changed conditions after consultation with the person(s) to whom this Hydraulic Project Approval is issued: PROVIDED HOWEVER, that such modifications shall be subject to appeal to the Hydraulic Appeals Board established in RCW 77.55.301.

## APPEALS INFORMATION

If you wish to appeal the issuance or denial of, or conditions provided in a Hydraulic Project Approval, there are informal and formal appeal processes available.

A. INFORMAL APPEALS (WAC 220-110-340) OF DEPARTMENT ACTIONS TAKEN PURSUANT TO RCW 77.55.021, 77.55.141, 77.55.181, and 77.55.291: A person who is aggrieved or adversely affected by the following Department actions may request an informal review of:

(A) The denial or issuance of a Hydraulic Project Approval, or the conditions or provisions made part of a Hydraulic Project Approval; or

(B) An order imposing civil penalties. A request for an INFORMAL REVIEW shall be in WRITING to the Department of Fish and Wildlife HPA Appeals Coordinator, 600 Capitol Way North, Olympia, Washington 98501-1091 and shall be RECEIVED by the Department within 30 days of the denial or issuance of a Hydraulic Project Approval or receipt of an order imposing civil penalties. If agreed to by the aggrieved party, and the aggrieved party is the Hydraulic Project Approval applicant, resolution of the concerns will be facilitated through discussions with the Area Habitat Biologist and his/her supervisor. If resolution is not reached, or the aggrieved party is not the Hydraulic Project Approval applicant, the Habitat Technical Services Division Manager or his/her designee shall conduct a review and recommend a decision to the Director or his/her designee. If you are not satisfied with the results of this informal appeal, a formal appeal may be filed.

B. FORMAL APPEALS (WAC 220-110-350) OF DEPARTMENT ACTIONS TAKEN PURSUANT TO RCW 77.55.021 (EXCEPT agricultural irrigation, stock watering or bank stabilization projects) or 77.55.291:
A person who is aggrieved or adversely affected by the following Department actions may request a formal review of:

(A) The denial or issuance of a Hydraulic Project Approval, or the conditions or provisions made part of a Hydraulic Project Approval;

(B) An order imposing civil penalties; or

(C) Any other 'agency action' for which an adjudicative proceeding is required under the Administrative Procedure Act, Chapter 34.05 RCW.

A request for a FORMAL APPEAL shall be in WRITING to the Department of Fish and Wildlife HPA Appeals Coordinator, shall be plainly labeled as 'REQUEST FOR FORMAL APPEAL' and shall be RECEIVED DURING OFFICE HOURS by the Department at 600 Capitol Way North, Olympia, Washington 98501-1091, within 30-days of the Department action that is being challenged. The time period for requesting a formal appeal is suspended during consideration of a timely informal appeal. If there has been an informal appeal, the deadline for requesting a formal appeal shall be within 30-days of the date of the Department's written decision in response to the informal appeal.

C. FORMAL APPEALS OF DEPARTMENT ACTIONS TAKEN PURSUANT TO RCW 77.55.021 (agricultural irrigation, stock watering or bank stabilization only), 77.55.141, 77.55.181, or 77.55.241: A person who is aggrieved or adversely affected by the denial or issuance of a Hydraulic Project Approval, or the conditions or provisions made part of a

Washington
Department of
FISH and
WILDLIFE

# HYDRAULIC PROJECT APPROVAL

RCW 77.55.021 - Appeal pursuant to Chapter 34.05 RCW

North Puget Sound
16018 Mill Creek Boulevard
Mill Creek, WA 98012-1296
(425) 775-1311

Issue Date: October 10, 2006 | Control Number: 107070-1

Project Expiration Date: October 09, 2011 | FPA/Public Notice #: N/A

---

Hydraulic Project Approval may request a formal appeal. The request for FORMAL APPEAL shall be in WRITING to the Hydraulic Appeals Board per WAC 259-04 at Environmental Hearings Office, 4224 Sixth Avenue SE, Building Two - Rowe Six, Lacey, Washington 98504; telephone 360/459-6327.

D. FORMAL APPEALS OF DEPARTMENT ACTIONS TAKEN PURSUANT TO CHAPTER 43.21L RCW: A person who is aggrieved or adversely affected by the denial or issuance of a Hydraulic Project Approval, or the conditions or provisions made part of a Hydraulic Project Approval may request a formal appeal. The FORMAL APPEAL shall be in accordance with the provisions of Chapter 43.21L RCW and Chapter 199-08 WAC. The request for FORMAL APPEAL shall be in WRITING to the Environmental and Land Use Hearings Board at Environmental Hearings Office, Environmental and Land Use Hearings Board, 4224 Sixth Avenue SE, Building Two - Rowe Six, P.O. Box 40903, Lacey, Washington 98504; telephone 360/459-6327.

E. FAILURE TO APPEAL WITHIN THE REQUIRED TIME PERIODS results in forfeiture of all appeal rights. If there is no timely request for an appeal, the department action shall be final and unappealable.

---

ENFORCEMENT: Sergeant Chandler (34) P3

| | | | |
|---|---|---|---|
| Habitat Biologist<br>Larry Fisher | 425-649-7042 | Larry Fisher | for Director<br>WDFW |

CC:

# APPENDIX M

## Chemical Material Safety Data Sheet

*This page intentionally left blank.*

# MATERIAL SAFETY DATA SHEET

## Chlorine

## SECTION 1 – CHEMICAL PRODUCT AND COMPANY IDENTIFICATION


**HOUSTON OFFICE**
700 Louisiana Street, Suite 4300
Houston, Texas 77002
U.S. • 1-800-423-4117

**MONTREAL OFFICE**
630 Rene Levesque Blvd. West, 31st Floor
Montreal, Quebec H3B 1S6
Canada • (514) 397-6100


**Product Name:** Chlorine
**CAS#:** 7782-50-5 **Major Update:** 11/11/05
**MSDS Code:** Cl2-e **Minor Revision:**
**Product Use:** Disinfection of water, plastics production, bleaching processes in pulp and paper, production of chlorinated compounds

### Emergency Contacts (24 hr.)

**FOR INFORMATION REGARDING ON SITE CHEMICAL EMERGENCIES INVOLVING A SPILL OR LEAK, CALL**

**U.S.: 1-800-424-9300 – CHEMTREC**
**Canada: 1-613-996-6666 – CANUTEC**

## SECTION 2 – COMPOSITION / INFORMATION ON INGREDIENTS

| Hazardous Ingredient(s) | % (w/w) | ACGIH | CAS NO. |
|---|---|---|---|
| Chlorine | 99 – 100 | TWA – 0.5 ppm<br>STEL - 1 ppm | 7782-50-5 |

## SECTION 3 – HAZARD IDENTIFICATION

**Emergency Overview:** Greenish-yellow gas or clear amber liquid (under pressure) with a pungent suffocating odor. COMPRESSED GAS. STRONG OXIDIZER. Contact with combustible materials may cause fire or explosion. Reacts violently or explosively with many substances. Reacts with water to form corrosive hydrochloric and hypochlorous acids. Confined space hazard. VERY TOXIC. May be fatal if inhaled. Extremely irritating to the respiratory tract. Causes lung injury and effects may be delayed. CORROSIVE to the eyes and skin. Liquefied gas can cause frostbite and corrosive injury to the eyes and skin. Burns and permanent damage, including blindness may result. Very toxic to aquatic organisms. Can cause damage to vegetation. Read the entire MSDS for a more thorough evaluation of the hazards.

**Potential Health Effects:**

**General:** Chlorine normally exists as a gas at room temperature and the most important route of exposure is inhalation, followed by eye and skin exposures. Liquefied chlorine can freeze skin tissues.

**Inhalation:** Chlorine is a severe nose, throat and upper respiratory tract irritant. People exposed to chlorine, even for short periods of time, can develop a tolerance to its odor and irritating properties. In mild exposures, clinical signs include rhinorrhea, cough, headache, sore throat, chest pain, dyspnea, nausea and pulmonary function deficits. After more severe exposures, clinical signs include rhinorrhea, ulcerative tracheobronchitis, pulmonary edema, respiratory failure and death.

The following is a listing of chlorine exposure thresholds and estimated clinical effects:

- 0.2 – 0.4 ppm – odor threshold (with considerable variation among subjects) (decrease in odor perception occurs over time).
- 5 – 15 ppm – moderate irritation of the respiratory tract
- 30 ppm – immediate chest pain, vomiting, dyspnea, cough
- 40 – 60 ppm – toxic pneumonitis and pulmonary edema
- 430 ppm – lethal over 30 minutes
- 1000 ppm – fatal within a few minutes

**Skin Contact:** Airborne gas may irritate and burn the skin. Direct contact with the liquefied gas escaping from its pressurized cylinder can cause frostbite. Symptoms of mild frostbite include numbness, prickling and itching in the affected area. Symptoms of more severe frostbite include a burning sensation and stiffness of the affected area. The skin may become waxy white or yellow.

**Eye Contact:** Chlorine gas is a severe eye irritant. Stinging, a burning sensation, rapid blinking, redness and watering of the eyes have been observed at concentrations of 1 ppm and higher. Direct contact with liquefied chlorine escaping from its high pressure cylinder may cause frostbite. Burns and permanent damage, including blindness may result.

**Ingestion:** Ingestion is not an applicable route of exposure for gases.

**Existing Medical Conditions Possibly Aggravated by Exposure:** Asthma, bronchitis, emphysema and other lung diseases and chronic nose, sinus or throat, and cardiac conditions.

**Chronic Effects:** A small number of human population studies conducted have not shown significant respiratory system effects in workers with long-term, low-level (typically less than 1 ppm) chlorine exposure. One study examined 332 workers exposed to time-weighted average (TWA) concentrations of between 0.006 and 1.42 ppm (0.15 ppm average) for an average of 10.9 years. No relationship was found between exposure to chlorine and the occurrence of colds, breathing difficulties, and abnormal heartbeat or chest pain. Significant effects on lung function were not observed. Studies of workers who have had experienced one or more exposures to chlorine which produced short-term health effects tend to show long-term lung dysfunction.

**Carcinogenicity:** Chlorine is not classified as carcinogenic by ACGIH (American Conference of Governmental Industrial Hygienists) or IARC (International Agency for Research on Cancer), not regulated as carcinogens by OSHA (Occupational Safety and Health Administration), and not listed as carcinogens by NTP (National Toxicology Program).

## SECTION 4 – FIRST AID MEASURES

**Inhalation:** Take proper precautions to ensure your own safety before attempting rescue (e.g., wear appropriate protective equipment, use the buddy system). Remove source of contamination or move victim to fresh air. If breathing is difficult, oxygen may be beneficial if administered by trained personnel, preferably on doctor's advice. DO NOT allow victim to move about unnecessarily. Symptoms of pulmonary edema can be delayed up to 48 hours after exposure. Apply artificial respiration if victim is not breathing. Induce artificial respiration with the aid of a pocket mask equipped with a one-way valve or other proper respiratory medical device. Give Cardiopulmonary Resuscitation (CPR) if there is no pulse AND no breathing. Obtain medical attention IMMEDIATELY.

**Skin Contact:** Quickly remove victim from source of contamination and flush with lukewarm, gently flowing water for a minimum of 20 minutes. Liquefied Gas: DO NOT attempt to rewarm the affected area on site. DO NOT rub area or apply dry heat. Gently remove clothing or jewelry that may restrict circulation. Carefully cut around clothing that sticks to the skin and remove the rest of the garment. Loosely cover the affected area with a sterile dressing. DO NOT allow victim to drink alcohol or smoke. Obtain medical attention IMMEDIATELY.

Δ **Eye Contact:** Immediately flush eyes with lukewarm running water for a minimum of 20 minutes. If a burn exists, cover both eyes with a sterile dressing. Liquified Gas: DO NOT attempt to rewarm the affected area on site. DO NOT rub area or apply dry heat. Loosely cover the affected area with a sterile dressing. DO NOT allow victim to drink alcohol or smoke. Obtain medical attention IMMEDIATELY.

**Ingestion:** Ingestion is not an applicable route of exposure for gases.

**Note to Physicians**: Following exposure the patient should be kept under medical review for at least 48 hours as delayed pulmonary edema may occur.

## SECTION 5 – FIRE FIGHTING MEASURES

| | |
|---|---|
| Δ **Flash Point** | Not applicable. Does not burn, but is a strong oxidizer and a serious fire risk. |
| **Flammable Limits (Lower)** | Not applicable |
| **Flammable Limits (Upper)** | Not applicable |
| **Auto Ignition Temperature** | Not applicable |
| **Decomposition Temperature** | Not available |
| **Combustion and Thermal Decomposition Products** | Toxic chemicals are formed when combustible materials burn in chlorine. These may include corrosive hydrogen chloride gas, free chlorine gas and other chlorine compounds. |
| **Rate of Burning** | Not applicable |
| **Explosive Power** | Not applicable |
| **Sensitivity to Mechanical Impact** | Not sensitive |
| Δ **Sensitivity to Static Discharge** | Specific information is not available. Liquefied chlorine can accumulate static charge by flow or agitation, since it has a very low electrical conductivity. |

**Fire and Explosion Hazards:** Chlorine does not burn. However, chlorine is a strong oxidizing agent and poses a serious fire and explosion risk because it promotes combustion, like oxygen. Most combustible materials will ignite and/or burn in chlorine atmospheres, forming irritating and toxic gases. Containers or cylinders may rupture violently due to over-pressurization, if exposed to fire or excessive heat for a sufficient period of time. Intense local heat (above 200°C) on the steel walls of chlorine cylinders can cause an iron/chlorine fire resulting in rupture of the container. Cylinder and ton containers will vent through fusible plugs at 71°C (160°F). Chlorine gas is heavier than air and will collect and persist in pits, hollows, depressions, and other confined or low-lying areas.

**Extinguishing Media:** Use extinguishing media appropriate to surrounding fire conditions, such as dry chemical powder, carbon dioxide, or foam.

**Fire Fighting Procedures:** Apply water from as far a distance as possible, in flooding quantities as a spray or fog to keep fire-exposed cylinders, containers or equipment cool and absorb heat, until well after the fire is out. If there is a chlorine leak, stop the flow of gas, if this can be done safely. A chlorine fire can be extinguished only by stopping the flow of chlorine gas. Use water spray to protect personnel attempting to shut off the flow. Remove all flammable and combustible materials from the vicinity, especially oil and grease. Use water with caution. Do not apply water directly to the liquefied or gaseous chlorine. Reverse flow into cylinder may cause rupture. Take care not to block pressure relief valves.

Stay away from ends of tanks (but realize that shrapnel may travel in any direction). In an advanced or massive fire, the area should be evacuated; use unmanned hoseholders or monitor nozzles.

**Fire Fighting Protective Equipment:** Use specialized protective equipment suitable for the situation. Firefighter's normal protective clothing (Bunker Gear) will not provide adequate protection. A full-body encapsulating chemical resistant suit with positive pressure self-contained breathing apparatus (MSHA/NIOSH approved or equivalent) may be necessary.

Evacuation: If tank, rail car or tank truck is involved in a fire, ISOLATE for 800 meters (½ mile) in all directions; also, consider initial evacuation for 800 meters (½ mile) in all directions.

**NOTE**: Also see « Section 10 - Stability and Reactivity ».

## SECTION 6 – ACCIDENTAL RELEASE MEASURES

**Spills, Leaks, or Releases:**

- Restrict access to area until completion of clean up. Ensure trained personnel conduct clean up.
- Wear adequate personal protective equipment including respiratory protection.
- Remove all combustible and flammable materials
- Remove all ignition sources (no smoking, flares, sparks or flames). All equipment should be grounded. Ventilate area.
- Stop leak if possible without personal risk. Emergency kits are available for handling chlorine leaks in cylinders, tank cars and tank trailers. All personnel must be trained in their particular usage. This information is available from the Chlorine Institute.
- Large leaks: Keep unauthorized personnel away. Stay upwind. Keep out of low areas. Prevent entry into sewers and confined areas. Vapor knock down water is corrosive and toxic, thus it should be diked for containment. Ensure compatible materials are used.
- Leaking cylinder: Only to be conducted by trained personnel. Emergency kits are available for handling leaking chlorine cylinders. Contents may also be disposed of to a safe out of doors area or a hood with forced ventilation. Attach appropriate control valve provided with a trap or check valve and a long piece of flexible hose connected to the valve outlet. Discharge the gas at a moderate rate into an adequate amount of about 15% aqueous sodium hydroxide or other alkali or reducing solution in suitable container. When all the gas is discharged, close the cylinder valve and tag the cylinder as defective. Dispose of waste according to local environmental regulations. Also, see "Section 7 - Handling and Storage".

**Deactivating Chemicals:** Sodium hydroxide; soda ash; hydrated lime - followed by a reducing agent. See Incompatibles in Section 10.

**Waste Disposal Methods:** Dispose of waste material at an approved waste treatment/disposal facility, in accordance with applicable regulations. Do not dispose of waste with normal garbage or to sewer systems.

Note - Clean-up material may be a RCRA Hazardous Waste on disposal.
- Releases are subject to CERCLA reporting requirements: RQ = 10 lb. (4.54 kg).

## SECTION 7 – HANDLING AND STORAGE

**Handling:** Take all precautions to avoid personal contact. Prevent the release of gas into workplace air. Always ensure adequate ventilation in handling areas. Locate safety shower and eyewash station close to chemical handling area. Keep away from incompatibles, heat, sparks, flames and other ignition sources. Locate safety shower and eyewash station fairly close to chemical handling area. Only auxiliary valves and gauges designed solely for chlorine gas should be used. Do NOT use stainless steel equipment. Open and shut valves to cylinders at least once a day, while cylinder is in use to avoid valve freezing. Secure containers at all times. Leaks should be fixed promptly. Vapors are heavier than air.

Prevent liquid or vapor from entering sewers, sumps or pit areas. Vapors can create a toxic atmosphere, which may be fatal. Use self-contained breathing apparatus to avoid suffocation.

**Storage:** Store in a cool, dry, well-ventilated area, out of direct sunlight, away from heat, away from flammable materials, incompatibles and away from process and handling areas. Do not store near elevators, corridors or loading docks. Do not store below ground level or in confined spaces. Storage area should be clearly identified, clear of obstruction and accessible only to trained and authorized personnel. Post warning signs. Inspect periodically for damage or leaks. Keep quantities stored as small as possible. For large-scale storage of this material consider the installation of a leak detection system with an alarm. Facilities for the emergency disposal of chlorine from leaking containers should be provided in storage areas. Avoid storage of cylinders for more than six months. Use the oldest first. Compressed gas cylinders should be stored separately according to their chemical hazards. This material is highly reactive. Always store in original labeled cylinder, or in the type of container recommended by the manufacturer/supplier. Keep cylinders tightly closed when not in use and when empty. Cylinder valves should be tightly closed. Cylinder valve caps should be properly secured. Always check cylinder valve for evidence of damage, rust or dirt, which may inhibit operation. Always chain or otherwise securely restrain cylinders in an upright position to a wall, rack or other solid structure when they are stored. Store empty cylinders separate from full ones with valves shut off, cap secure and labeled EMPTY or "MT". Empty containers may contain hazardous residues.

Outdoor cylinder storage should be weatherproofed and have proper drainage. Have appropriate fire extinguishers and leak clean-up equipment in storage area.

**Storage Temperature:** Protect from temperature extremes. (Never expose cylinders to temperatures higher than 52°C (125°F) or below -29°C (-20°F) unless they are designed for this.

**Other Precautions:** Walls, floors, shelving, fittings, lighting and ventilation systems in storage area should be made from materials that do not react with chlorine. Below 121°C (250°F), iron, copper, steel, lead, nickel, platinum, silver and tantalum are resistant to dry chlorine gas or liquid. Storage facilities should be made of fire-resistant materials.

## SECTION 8 – EXPOSURE CONTROLS / PERSONAL PROTECTION

### PREVENTIVE MEASURES

**Recommendations listed in this section indicate the type of equipment, which will provide protection against over exposure to this product. Conditions of use, adequacy of engineering or other control measures, and actual exposures will dictate the need for specific protective devices at your workplace.**

**Engineering Controls:** Local exhaust ventilation should be applied wherever there is an incidence of point source emissions or dispersion of regulated contaminants in the work area. The most effective measures are the total enclosure of processes and the mechanization of handling procedures to prevent all personal contact with chlorine. Because of the high potential hazard associated with this substance, stringent control measures such as enclosure or isolation are recommended when dealing with large quantities. Systems must be kept "dry" to prevent metal corrosion.

### PERSONAL PROTECTIVE EQUIPMENT

**Eye Protection:** Use full face-shield and chemical safety goggles when there is potential for contact. Maintain eye wash fountain and quick-drench facilities in work area.

**Skin Protection:** If contact with liquid or gas is possible, then use chemical protective gloves, coveralls, boots and/or other resistant protective clothing. Have a safety shower/eye-wash fountain readily available in the immediate work area. Some operations may require the use of a chemical protective full-body encapsulating suit and respiratory protection.

***Resistance of Materials for Protective Clothing:***

Guidelines for chlorine, liquid:

- RECOMMENDED (resistance to breakthrough longer than 8 hours): Responder ™, Tychem 10000 ™.

Guidelines for chlorine, gas:

- RECOMMENDED (resistance to breakthrough longer than 8 hours): Butyl rubber, Neoprene, Teflon ™, Viton ™, Saranex ™, Barricade ™, CPF 3 ™, Responder ™, Trellchem HPS ™, Tychem 10 000 ™.
- RECOMMENDED (resistance to breakthrough longer than 4 hours): Nitrile rubber, 4H ™ (PE/EVAL).
- NOT RECOMMENDED for use (resistance to breakthrough less than 1 hour): Polyethylene, Polyvinyl Chloride.

Recommendations are NOT valid for very thin Natural rubber, Neoprene, Nitrile and PVC gloves (0.3 mm or less).

Recommendations are valid for permeation rates reaching 0.1 ug/cm$^2$/min or 1 mg/m$^2$/min and over. Resistance of specific materials can vary from product to product. Breakthrough times are obtained under conditions of continuous contact, generally at room temperature. Evaluate resistance under conditions of use and maintain clothing carefully.

**Respiratory Protection:** *NIOSH recommendations for chlorine concentrations in air*:

- UP TO 5 ppm: Chemical cartridge respirator with cartridge(s) to protect against chlorine; or supplied-air respirator (SAR).
- UP TO 10 ppm: SAR operated in a continuous flow mode*; or powered air-purifying respirator with cartridge(s) to protect against chlorine; or full face-piece chemical cartridge respirator with cartridge(s) to protect against chlorine; or gas mask with canister to protect against chlorine; or full face-piece self-contained breathing apparatus (SCBA); or full face-piece SAR.
- Emergency or planned entry in unknown concentration or Immediately Dangerous to Life or Health (IDLH) conditions: Positive pressure, full face-piece SCBA; or positive pressure, full face-piece SAR with an auxiliary positive pressure SCBA.
- Escape: Mouth bit or cartridge respirator with approved chlorine cartridge; or gas mask with canister to protect against chlorine; or escape-type SCBA.

* NOTE: may require eye protection.

## EXPOSURE GUIDELINES

**PRODUCT: Chlorine**

| | |
|---|---|
| ACGIH Time Weighted Average (TLV-TWA) | 0.5 ppm (1.5 mg/m$^3$) |
| ACGIH Short Term Exposure Limit (STEL) | 1.0 ppm (3.0 mg/m$^3$) |
| OSHA Time Weighted Average (PEL-TWA) | 1.0 ppm (3.0 mg/m$^3$) |
| Immediately Dangerous to Life and Health (IDLH): | 10 ppm |

AIHA- Emergency Response Planning Guidelines (ERPGs)

*ERPGs are for community emergency planning limits and not workplace exposure limits.*

- ERPG-1: 1 ppm
- ERPG-2: 3 ppm
- Δ ERPG-3: 20 ppm

The **ERPG-1** is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hr without experiencing other than mild transient adverse health effects or perceiving a clearly defined, objectionable odor.

The **ERPG-2** is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hr without experiencing or developing irreversible or other serious health effects or symptoms, which could impair an individual's ability to take protective action.

The **ERPG-3** is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hr without experiencing or developing life-threatening health effects.

## SECTION 9 – PHYSICAL AND CHEMICAL PROPERTIES

| | |
|---|---|
| **Alternate Name(s)** | Molecular chlorine |
| **Chemical Name** | Chlorine |
| **Chemical Family** | Halogen |
| **Molecular Formula** | $Cl_2$ |
| **Molecular Weight** | 70.9 |
| **Appearance** | Yellowish-green gas or clear amber colored liquid when liquefied. |
| **Odor** | Pungent odor |
| **pH** | 1.5-2.0 (0.8% Aqueous Solution) |
| **% Volatile by Volume** | 100 |
| **Vapor Pressure** | 673.1 kPa (6.64 atm) (97.6 psig) at (20°C); 1427 kPa (14.1 atm.) (207 psig) 5830 mm Hg @ 25°C (77°F) |
| **Vapor Density (Air = 1)** | 2.47 |
| **Boiling Point** | -29°F (-34°C) |
| Δ **Freezing/Melting Point** | -150°F (-101°C) |
| **Solubility (Water) 68°F** | 0.7% |
| **Specific Gravity** | 1.467 at 0°C (32°F) and 368.9 kPa (saturated liquefied gas); 0.0032 at 0°C (gas) (water = 1) |
| **Critical Temperature** | 291.2°F (143.75°C) |
| **Viscosity** | Liquefied gas – 0.346 mPa.s at 20°C (68°F) |
| Δ **Coefficient of Oil/Water distribution** | Not Available |

## SECTION 10 – STABILITY AND REACTIVITY

**Hazardous Decomposition Products:** Chlorine reacts with water to form a corrosive solution of hydrochloric acid and hypochlorous acid, which can decompose to chlorine, oxygen and chloric acid.

**Chemical Stability:** Stable at room temperature

**Conditions to Avoid:** Temperatures greater than 121°C (250°F), and moisture.

**Incompatibility with other Substances:** Chlorine gas can react explosively with alcohols, ammonia and compounds, hydrocarbon gases (e.g. acetylene and ethylene), hydrogen, antimony trichloride and tetramethylsilane, aziridine, bromine pentafluoride, dioxygen difluoride, oxygen difluoride, fluorine, diborane, dichloro(methyl)arsine, disilyl oxide, ethylphosphine, strong reducing agents, aqueous sulfamic acid, stibine, synthetic rubber, tetraselenium tetranitride and white phosphorus.

Chlorine gas ignites on contact with mono and di-alkali metal acetylides, copper acetylides, halocarbons (e.g. dichloromethane), metals (e.g. finely powdered aluminum, brass and copper foil, iron, potassium, sodium, tin and titanium), non-metals (e.g. boron, active carbon, phosphorous and silicon), iron, uranium and zirconium carbides, diethyl ether, diethyl zinc, metal and non-metal hydrides, phosphorus compounds, sulfides, tellurium, trialkyl boranes and tungsten dioxide.

Liquefied chlorine can react violently, explosively or ignite on contact with carbon disulfide, iron, bismuth, dibutyl phthalate, drawing wax, gasoline, glycerol, linseed oil, white phosphorus, polydimethylsiloxane, silicones, sodium hydroxide, tin, titanium and vanadium powder.

**Corrosivity To Metals:** At ordinary temperatures, dry chlorine is not corrosive to most common metals, including steel, stainless steel, cast iron, nickel and its alloys, copper, brass, bronze, lead, platinum and tantalum. Dry chlorine attacks aluminum, tin and titanium at ordinary temperatures and is corrosive to most metals at high temperatures (121°C and up). Moist chlorine is strongly corrosive to most common metals. Platinum, tantalum and titanium are resistant. Tantalum is the most stable metal to both dry and wet chlorine.

**Hazardous Polymerization:** Will not occur.

## SECTION 11 – TOXICOLOGICAL INFORMATION

### TOXICOLOGICAL DATA

| | | | |
|---|---|---|---|
| **Toxicological Data:** | Chlorine: | $LC_{50}$ rat | 147 ppm (4-hour exposure) |
| | | | 293 ppm (1-hour exposure) |
| | | | 690 ppm (30-minute exposure) |
| | | $LC_{50}$ mouse | 70 ppm (4 hr exposure) |
| Δ | | | 137 ppm (1 hr exposure) |

**Mutagenicity:** No human data available

**Reproductive Effects:** One report indicates that pregnant women occupationally exposed to chlorine had normal pregnancies.

**Teratogenicity and Fetotoxicity:** No evidence

Δ **Synergistic Materials:** No information available.

## SECTION 12 – ECOLOGICAL INFORMATION

**Ecotoxicological Information:** Chlorine is highly toxic to all forms of aquatic life. There is no potential for bioaccumulation or bioconcentration. Aquatic Fate: The stability of free chlorine in natural water is very low because it is a strong oxidizing agent and rapidly oxidizes inorganic compounds. It also oxidizes organic compounds, but more slowly than inorganic compounds.

| | |
|---|---|
| Fish Toxicity: | emerald shiner $LC_{50}$: 230 ug/L/96 hrs,<br>rainbow trout $LC_{50}$: 172 ug/L/96hrs,<br>cohoe salmon $LC_{50}$: 289 ug/L/96 hrs |
| Invertebrate Toxicity: | $LC_{50}$: 637.5 ug/L/1 hour (mortality) Pacific oyster (Crassostrea gigas) |
| Plant Toxicity: | 20 ug/L/96 days (growth) Water-milfoil (Myriophyllum spicatum) |

## SECTION 13 – DISPOSAL CONSIDERATIONS

Review federal, state and local government requirements prior to disposal.

Do not dispose of waste with normal garbage, or to sewer systems.

Whatever cannot be saved for recovery or recycling, including containers should be managed in an appropriate and approved waste disposal facility. Processing, use or contamination of this product may change the waste management options.

**RCRA:** Test waste material for corrosivity, D002, prior to disposal.

## SECTION 14 – TRANSPORT INFORMATION

| | TDG CLR * | DOT |
|---|---|---|
| **Shipping Name** | Chlorine | Chlorine |
| **Hazard Class / Division** | 2.3<br>8 | 2.3<br>8 |
| **Identification No.** | UN 1017 | UN 1017 |
| Δ **Reportable Quantity** | Not Applicable | RQ: 10 lbs (4.54 Kg) |
| Δ **ERAP** | 500 L | Not Applicable |

**Note: * TDG CLR (Clear Language Regulations) became effective August 15, 2002**

**TDG –** Emergency Response Assistance Planning (ERAP) requirements of sections 7 must be met for quantities exceeding 500 liters in one means of containment.

**DOT–** Other Classification: Marine pollutant. This material is poisonous by inhalation in Hazard Zone B (SPECIAL LABEL/PLACARD REQUIRED)

**IATA/ICAO Shipping Description**: Chlorine, Class 2.3 (8), UN1017 is forbidden for air transport except with prior approval of Transport Canada or DOT.

Δ **CERCLA RQ** = 10 lbs (4.54 Kg).

**For Chemical Emergencies In Transportation Requiring Activation Of Pioneer 24 Hour Emergency Response Plan Call:**
**U.S. 1-800-424-9300 – Chemtrec**
**Canada 1-819-294-6633**

## SECTION 15 – REGULATORY INFORMATION

Δ **CANADIAN CLASSIFICATION**

**This product has been classified in accordance with the hazard criteria of the CPR (Controlled Products Regulations) and this MSDS (Material Safety Data Sheet) contains all the information required by the CPR.**

Δ **Controlled Products Regulations (WHMIS) Classification:**
A – Compressed gas
D1A – Poisonous and infectious material – Immediate and serious effects – Very toxic
D2A – Poisonous and infectious material – Other effects – Very toxic
E – Corrosive material

**WHMIS Health Effects:**
Acute lethality – very toxic – immediate
TDG class 2.3 – very toxic – immediate
Chronic toxicity – very toxic – other
Corrosive to skin

**CEPA / Canadian Domestic Substances List (DSL):** On the Canadian Domestic Substances List (CEPA DSL).

Δ **WHMIS Ingredient Disclosure List:** Meets criteria for disclosure at 1% or greater.

**National Pollutant Release Inventory (NPRI) 2001:** It is listed on Part 1 of Schedule 1. Information about this substance must be reported to the Minister of the Environment in accordance with subsection 16(1) of the Canadian Environmental Protection Act.

Δ **USA CLASSIFICATION**

**OSHA Classification:** Meets Criteria for hazardous material 29CFR 1910.1200 and Highly Hazardous Chemicals, Code of Federal Regulations (CFR) v.29 Part 1910, Section 1910.119
Threshold Quantity = 1500 lbs.

**TSCA Inventory Status:** Y

**SARA Regulations sections 313 and 40 CFR 372:** Y

**SARA Hazard Categories, SARA SECTIONS 311/312 (40CFR370.21):**
ACUTE: Y
CHRONIC: N
FIRE: Y
REACTIVE: N
SUDDEN RELEASE: Y
OSHA PROCESS SAFETY (29CFR1910.119): Y

**CERCLA Reportable Quantity:** RQ = 10 lbs.
Threshold Planning Limit = 100 lbs.
This product does not contain nor is it manufactured with ozone depleting substances.

**Other Regulations/Legislation which apply to this product:**
Michigan Critical Materials Register: Y

**Right-To-Know:** Illinois, Massachusetts, New Jersey, Pennsylvania

**EEC Classification:** Toxic. Irritant. Dangerous for environment.

**EINECS:** 231-959-5

## SECTION 16 – OTHER INFORMATION

**The information contained herein is offered only as a guide to the handling of this specific material and has been prepared in good faith by technically knowledgeable personnel. It is not intended to be all-inclusive and the manner and conditions of use and handling may involve other and additional considerations. No warranty of any kind is given or implied and PIONEER will not be liable for any damages, losses, injuries or consequential damages that may result from the use of or reliance on any information contained herein. This Material Safety Data Sheet is valid for three years.**

**Revision Indicators:**

Δ In the left margin indicates a revision or addition of information since the previous issue.

**National Fire Protection Association (NFPA) Rating**
**Hazardous Materials Identification System (HMIS) Rating**

| | NFPA | HMIS |
|---|---|---|
| Δ HEALTH | 4 | 4 |
| FIRE | 0 | 0 |
| REACTIVITY | 0 | 0 |
| SPECIAL | oxidizer | |

4 = Extreme/Severe
3 = High/Serious
2 = Moderate
1 = Slight
0 = Minimum

## REFERENCE

1. RTECS-Registry of Toxic Effects of Chemical Substances, Canadian Centre for Occupational Health and Safety RTECS database, National Institute for Occupational Safety and Health, U.S. Dept. of Health and Human Services, Cincinnati, Entry Update/ May 2005
2. Transport Of Hazardous Materials (49CFR), Canadian Centre for Occupational Health and Safety, Issue : 2005
3. The Chlorine Institute, Inc., "Molecular Chlorine: Health and Environmental Effects", Pamphlet 90, Edition 2, November 1998
4. "CHEMINFO", CCOHS, Canadian Centre for Occupational Health and Safety, Hamilton, Ontario, Canada, (May, 2005).
5. Chemlist, STN Database, Chemical Abstract Service, 2005
6. Chemical Hazards Response Information System (CHRIS), CCOHS, May 2002.
7. HSDB-Hazardous Substances Data Bank , through "CCINFO disc", Canadian Centre for Occupational Health and Safety, Hamilton, Ontario, Canada, (May, 2002).
8. NFPA 49 Hazardous Chemicals Data 1994 Edition, National Fire Protection Association, Quincy, MA, 1994
9. NIOSH POCKET GUIDE TO CHEMICAL HAZARDS, U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health, June 1997
10. "2005 Threshold Limit Values and Biological Exposure Indices", American Conference of Government Industrial Hygienists, 2005.
11. TRANSPORT OF DANGEROUS GOODS (TDG), Canadian Centre for Occupational Health and Safety, * Issue : 2005

## LEGEND

ACGIH - American Conference of Governmental Industrial Hygienists
AFFF - Aqueous Film Forming Foam
CAS # - Chemical Abstracts Service Registry Number
CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act
CFR - Code of Federal Regulations
DOT - Department of Transportation
EPA - Environmental Protection Agency
LC50 - The concentration of material in air expected to kill 50% of a group of test animals
MSHA - Mine Safety and Health Administration
NIOSH - National Institute for Occupational Safety and Health
OSHA - Occupational Safety & Health Administration
PEL - Permissible Exposure Limit
PVC - Polyvinyl chloride
RCRA - Resource Conservation and Recovery Act
SARA - Superfund Amendments and Reauthorization Act of the U.S. EPA
TDG - Transportation of Dangerous Goods Act/Regulations
TLV - Threshold Limit Value
TSCA - Toxic Substances Control Act
TWA - Time-Weighted Average

005 02/07/07 SODIUM FLUORIDE

PRODUCT NAME: SODIUM FLUORIDE

MSDS NUMBER: MZS3722

DATE ISSUED: 8/27/2004

SUPERSEDES: 1/23/2002

ISSUED BY: 008614

This MSDS was reviewed on 02/07/2007, and is current as of the DATE ISSUED above.

==========

SODIUM FLUORIDE

==========

## 1. PRODUCT IDENTIFICATION

SYNONYMS: FLORIDINE; SODIUM MONOFLUORIDE; DISODIUM DIFLUORIDE; NATRIUM FLUORIDE; FLOROCID
CAS NO: 7681-49-4
MOLECULAR WEIGHT: 41.99
CHEMICAL FORMULA: NAF

Distributed by:
Univar USA Inc.
17425 NE Union Hill Road
Redmond, WA 98052
425-889-3400

==========

## 2. COMPOSITION/INFORMATION ON INGREDIENTS

| INGREDIENT | CAS NO | PERCENT | HAZARDOUS |
|---|---|---|---|
| SODIUM FLUORIDE | 7681-49-4 | 100% | YES |

==========

## 3. HAZARDS IDENTIFICATION

### EMERGENCY OVERVIEW

DANGER! MAY BE FATAL IF SWALLOWED OR INHALED. AFFECTS RESPIRATORY SYSTEM, HEART, SKELETON, CIRCULATORY SYSTEM, CENTRAL NERVOUS SYSTEM AND KIDNEYS. CAUSES IRRITATION TO SKIN, EYES AND RESPIRATORY TRACT. IRRITATION EFFECTS MAY BE DELAYED.

### POTENTIAL HEALTH EFFECTS

IF INHALED OR SWALLOWED, THIS COMPOUND CAN CAUSE FLUORIDE POISONING. EARLY SYMPTOMS INCLUDE NAUSEA, VOMITING, DIARRHEA, AND WEAKNESS. LATER EFFECTS INCLUDE CENTRAL NERVOUS SYSTEM EFFECTS, CARDIOVASCULAR EFFECTS AND DEATH.

INHALATION:
CAUSES SEVERE IRRITATION TO THE RESPIRATORY TRACT, SYMPTOMS MAY INCLUDE COUGHING, SORE THROAT, AND LABORED BREATHING. MAY BE ABSORBED THROUGH INHALATION OF DUST; SYMPTOMS MAY PARALLEL THOSE FROM INGESTION EXPOSURE. IRRITATION EFFECTS MAY NOT APPEAR IMMEDIATELY.

INGESTION:

TOXIC! MAY CAUSE SALIVATION, NAUSEA, VOMITING, DIARRHEA, AND ABDOMINAL PAIN. SYMPTOMS OF WEAKNESS, TREMORS, SHALLOW RESPIRATION, CARDOPEDAL SPASM, CONVULSIONS, AND COMA MAY FOLLOW. MAY CAUSE BRAIN AND KIDNEY DAMAGE. AFFECTS HEART AND CIRCULATORY SYSTEM. DEATH MAY OCCUR FROM RESPIRATORY PARALYSIS. ESTIMATED LETHAL DOSE = 5-L0 GRAMS.

SKIN CONTACT:
CAUSES IRRITATION, WITH REDNESS AND PAIN. SOLUTIONS ARE CORROSIVE. EFFECTS MAY NOT APPEAR IMMEDIATELY.

EYE CONTACT:
EYE IRRITANT! MAY CAUSE IRRITATION AND SERIOUS EYE DAMAGE. EFFECTS MAY NOT IMMEDIATELY APPEAR.

CHRONIC EXPOSURE:
CHRONIC EXPOSURE MAY CAUSE MOTTLING OF TEETH AND BONE DAMAGE (OSTEOSCLEROSIS) AND FLUOROSIS. SYMPTOMS OF FLUORISIS INCLUDE BRITTLE BONES,WEIGHT LOSS, ANEMIA, CALCIFIED LIGAMENTS, GENERAL ILL HEALTH AND JOINT STIFFNESS.

AGGRAVATION OF PRE-EXISTING CONDITIONS:
POPULATIONS THAT APPEAR TO BE AT INCREASED RISK FROM THE EFFECTS OF FLUORIDE ARE INDIVIDUALS THAT SUFFER FROM DIABETES INSIPIDUS OR SOME FORMS OF RENAL IMPAIRMENT.

==========

## 4. FIRST AID MEASURES

FIRST AID PROCEDURES SHOULD BE PRE-PLANNED FOR FLUORIDE COMPOUND EMERGENCIES.

INHALATION:
IF INHALED, REMOVE TO FRESH AIR. IF NOT BREATHING, GIVE ARTIFICIAL RESPIRATION. IF BREATHING IS DIFFICULT, GIVE OXYGEN. CALL A PHYSICIAN IMMEDIATELY.

INGESTION:
ADMINISTER MILK, CHEWABLE CALCIUM CARBONATE TABLETS OR MILK OF MAGNESIA. NEVER GIVE ANYTHING BY MOUTH TO AN UNCONSCIOUS PERSON. CALL A PHYSICIAN IMMEDIATELY.

SKIN CONTACT:
WIPE OFF ANY EXCESS MATERIAL FROM SKIN AND THEN IMMEDIATELY FLUSH SKIN WITH LARGE AMOUNTS OF SOAPY WATER. REMOVE CONTAMINATED CLOTHING AND SHOES. WASH CLOTHING BEFORE RE-USE. APPLY BANDAGES SOAKED IN MAGNESIUM SULFATE. CALL A PHYSICIAN IMMEDIATELY.

EYE CONTACT:
IMMEDIATELY FLUSH EYES WITH GENTLE BUT LARGE STREAM OF WATER FOR AT LEAST 15 MINUTES, LIFTING LOWER AND UPPER EYELIDS OCCASIONALLY. CALL A PHYSICIAN IMMEDIATELY.

NOTE TO PHYSICIAN:
FOR LARGE EXPOSURES, SYSTEMIC EFFECTS (HYPOCALCEMIA AND HYPOMAGNESIA) MAY OCCUR.

==========

## 5. FIRE FIGHTING MEASURES

FIRE:
NOT CONSIDERED TO BE A FIRE HAZARD.

EXPLOSION:
NOT CONSIDERED TO BE AN EXPLOSION HAZARD.

FIRE EXTINGUISHING MEDIA:
USE ANY MEANS SUITABLE FOR EXTINGUISHING SURROUNDING FIRE.

SPECIAL INFORMATION:
IN THE EVENT OF A FIRE, WEAR FULL PROTECTIVE CLOTHING AND NIOSH-APPROVED SELF-CONTAINED BREATHING APPARATUS WITH FULL FACEPIECE OPERATED IN THE PRESSURE DEMAND OR OTHER POSITIVE PRESSURE MODE.

==========

## 6. ACCIDENTAL RELEASE MEASURES

VENTILATE AREA OF LEAK OR SPILL. WEAR APPROPRIATE PERSONAL PROTECTIVE EQUIPMENT AS SPECIFIED IN SECTION 8. SPILLS: PICK UP AND PLACE IN A SUITABLE CONTAINER FOR RECLAMATION OR DISPOSAL, USING A METHOD THAT DOES NOT GENERATE DUST. US REGULATIONS (CERCLA) REQUIRE REPORTING SPILLS AND RELEASES TO SOIL, WATER AND AIR IN EXCESS OF REPORTABLE QUANTITIES. THE TOLL FREE NUMBER FOR THE US COAST GUARD NATIONAL RESPONSE CENTER IS (800) 424-8802.

==========

## 7. HANDLING AND STORAGE

KEEP IN A TIGHTLY CLOSED CONTAINER, STORED IN A COOL, DRY, VENTILATED AREA. PROTECT AGAINST PHYSICAL DAMAGE. SEPARATE FROM ACIDS AND OXIDIZING MATERIALS. CONTAINERS OF THIS MATERIAL MAY BE HAZARDOUS WHEN EMPTY SINCE THEY RETAIN PRODUCT RESIDUES (DUST, SOLIDS); OBSERVE ALL WARNINGS AND PRECAUTIONS LISTED FOR THE PRODUCT.

==========

## 8. EXPOSURE CONTROLS/PERSONAL PROTECTION

AIRBORNE EXPOSURE LIMITS:
-OSHA PERMISSIBLE EXPOSURE LIMIT (PEL):
2.5 MG(F)/M3 (TWA)

-ACGIH THRESHOLD LIMIT VALUE (TLV):
2.5 MG(F)/M3 (TWA)

VENTILATION SYSTEM:
A SYSTEM OF LOCAL AND/OR GENERAL EXHAUST IS RECOMMENDED TO KEEP EMPLOYEE EXPOSURES BELOW THE AIRBORNE EXPOSURE LIMITS. LOCAL EXHAUST VENTILATION IS GENERALLY PREFERRED BECAUSE IT CAN CONTROL THE EMISSIONS OF THE CONTAMINANT AT ITS SOURCE, PREVENTING DISPERSION OF IT INTO THE GENERAL WORK AREA. PLEASE REFER TO THE ACGIH DOCUMENT, "INDUSTRIAL VENTILATION, A MANUAL OF RECOMMENDED PRACTICES", MOST RECENT EDITION, FOR DETAILS.

PERSONAL RESPIRATORS (NIOSH APPROVED):
IF THE EXPOSURE LIMIT IS EXCEEDED AND ENGINEERING CONTROLS ARE NOT FEASIBLE, A HALF FACEPIECE PARTICULATE RESPIRATOR (NIOSH TYPE N95 OR BETTER FILTERS) MAY BE WORN FOR UP TO TEN TIMES THE EXPOSURE LIMIT OR THE MAXIMUM USE CONCENTRATION SPECIFIED BY THE APPROPRIATE REGULATORY AGENCY OR RESPIRATOR SUPPLIER, WHICHEVER IS LOWEST.. A FULL-FACE PIECE PARTICULATE RESPIRATOR (NIOSH TYPE N100 FILTERS) MAY BE WORN UP TO 50 TIMES THE EXPOSURE LIMIT, OR THE MAXIMUM USE CONCENTRATION SPECIFIED BY THE APPROPRIATE REGULATORY AGENCY, OR RESPIRATOR SUPPLIER, WHICHEVER IS LOWEST. IF OIL PARTICLES (E.G. LUBRICANTS, CUTTING FLUIDS, GLYCERINE, ETC.) ARE PRESENT, USE A NIOSH TYPE R OR P FILTER. FOR EMERGENCIES OR INSTANCES WHERE THE EXPOSURE LEVELS ARE NOT KNOWN, USE A FULL-FACEPIECE POSITIVE-PRESSURE, AIR-SUPPLIED RESPIRATOR. WARNING: AIR-PURIFYING RESPIRATORS DO NOT PROTECT WORKERS IN OXYGEN-DEFICIENT ATMOSPHERES.

SKIN PROTECTION:

WEAR IMPERVIOUS PROTECTIVE CLOTHING, INCLUDING BOOTS, GLOVES, LAB COAT, APRON OR COVERALLS, AS APPROPRIATE, TO PREVENT SKIN CONTACT.

EYE PROTECTION:
USE CHEMICAL SAFETY GOGGLES AND/OR FULL FACE SHIELD WHERE DUSTING OR SPLASHING OF SOLUTIONS IS POSSIBLE. MAINTAIN EYE WASH FOUNTAIN AND QUICK-DRENCH FACILITIES IN WORK AREA.

==========

## 9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE:
WHITE CRYSTALS.

ODOR:
ODORLESS.

SOLUBILITY:
4 G/100 ML WATER @ 15C (59F)

SPECIFIC GRAVITY:
2.78

PH:
NO INFORMATION FOUND.

% VOLATILES BY VOLUME @ 21C (70F):
0

BOILING POINT:
1700C (3092F)

MELTING POINT:
993C (1819F)

VAPOR DENSITY (AIR=1):
NO INFORMATION FOUND.

VAPOR PRESSURE (MM HG):
1 @ 1077C (1971F)

EVAPORATION RATE (BUAC=1):
NO INFORMATION FOUND.

==========

## 10. STABILITY AND REACTIVITY

STABILITY:
STABLE UNDER ORDINARY CONDITIONS OF USE AND STORAGE.

HAZARDOUS DECOMPOSITION PRODUCTS:
BURNING MAY PRODUCE HYDROGEN FLUORIDE VAPORS.

HAZARDOUS POLYMERIZATION:
WILL NOT OCCUR.

INCOMPATIBILITIES:
REACTS WITH ACIDS TO FORM HYDROGEN FLUORIDE.

CONDITIONS TO AVOID:
NO INFORMATION FOUND.

==========

## 11. TOXICOLOGICAL INFORMATION

ORAL RAT LD50: 52 MG/KG; EYE RABBIT (STANDARD DRAIZE) 20MG/24-HR, MODERATE; INVESTIGATED AS A TUMORIGEN, MUTAGEN, REPRODUCTIVE EFFECTOR

---------/CANCER LISTS/----------

| INGREDIENT | ---NTP CARCINOGEN--- KNOWN | ANTICIPATED | IARC CATEGORY |
|---|---|---|---|
| SODIUM FLUORIDE (7681-49-4) | NO | NO | NONE |

==========

## 12. ECOLOGICAL INFORMATION

ENVIRONMENTAL FATE:
NO INFORMATION FOUND.

ENVIRONMENTAL TOXICITY:
THIS MATERIAL IS NOT EXPECTED TO BE TOXIC TO AQUATIC LIFE. THE LC50/96-HOUR VALUES FOR FISH ARE OVER 100 MG/L. LD50, ORAL (GOAT, SHEEP) 100 MG/KG; LD50, ORAL (WILD BIRD) 110 MG/KG.

==========

## 13. DISPOSAL CONSIDERATIONS

WHATEVER CANNOT BE SAVED FOR RECOVERY OR RECYCLING SHOULD BE MANAGED IN AN APPROPRIATE AND APPROVED WASTE DISPOSAL FACILITY. PROCESSING, USE OR CONTAMINATION OF THIS PRODUCT MAY CHANGE THE WASTE MANAGEMENT OPTIONS. STATE AND LOCAL DISPOSAL REGULATIONS MAY DIFFER FROM FEDERAL DISPOSAL REGULATIONS.

DISPOSE OF CONTAINER AND UNUSED CONTENTS IN ACCORDANCE WITH FEDERAL, STATE AND LOCAL REQUIREMENTS.

==========

## 14. TRANSPORT INFORMATION

DOMESTIC (LAND, D.O.T.)

PROPER SHIPPING NAME: SODIUM FLUORIDE
HAZARD CLASS: 6.1
UN/NA: UN1690 PACKING GROUP: III

INTERNATIONAL (WATER, I.M.O.)

PROPER SHIPPING NAME: SODIUM FLUORIDE, SOLID
HAZARD CLASS: 6.1
UN/NA: UN1690 PACKING GROUP: III

==========

## 15. REGULATORY INFORMATION

/CHEMICAL INVENTORY STATUS - PART 1/

| INGREDIENT | TSCA | EC | JAPAN | AUSTRALIA |
|---|---|---|---|---|
| SODIUM FLUORIDE (7681-49-4) | YES | YES | YES | YES |

/CHEMICAL INVENTORY STATUS - PART 2/

| INGREDIENT | KOREA | --CANADA-- DSL | NDSL | PHIL. |
|---|---|---|---|---|
| SODIUM FLUORIDE (7681-49-4) | YES | YES | NO | YES |

/FEDERAL, STATE & INTERNATIONAL REGULATIONS - PART 1/

| INGREDIENT | -SARA 302- RQ | TPQ | ------SARA 313----- LIST | CHEMICAL CATG |
|---|---|---|---|---|
| SODIUM FLUORIDE (7681-49-4) | NO | NO | NO | NO |

/FEDERAL, STATE & INTERNATIONAL REGULATIONS - PART 2/

| INGREDIENT | CERCLA | -RCRA- 261.33 | -TSCA- 8(D) |
|---|---|---|---|
| SODIUM FLUORIDE (7681-49-4) | 1000 | NO | NO |

CHEMICAL WEAPONS CONVENTION: YES TSCA 12(B): NO CDTA: NO
SARA 311/312: ACUTE: YES CHRONIC: YES FIRE: NO PRESSURE: NO

REACTIVITY: NO (PURE / SOLID)

AUSTRALIAN HAZCHEM CODE: 2Z
POISON SCHEDULE: S2

WHMIS: THIS MSDS HAS BEEN PREPARED ACCORDING TO THE HAZARD CRITERIA OF THE CONTROLLED PRODUCTS REGULATIONS (CPR) AND THE MSDS CONTAINS ALL OF THE INFORMATION REQUIRED BY THE CPR.

==========

16. OTHER INFORMATION

NFPA RATINGS:
HEALTH: 3 FLAMMABILITY: 0 REACTIVITY: 0

---------- FOR ADDITIONAL INFORMATION ----------

CONTACT: MSDS COORDINATOR UNIVAR USA INC.
DURING BUSINESS HOURS, PACIFIC TIME (425)889-3400

---------- NOTICE ----------

********** UNIVAR USA INC ("UNIVAR") EXPRESSLY DISCLAIMS

---

ALL EXPRESS OR IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A

---

PARTICULAR PURPOSE, WITH RESPECT TO THE PRODUCT OR INFORMATION PROVIDED HEREIN,

---

AND SHALL UNDER NO CIRCUMSTANCES BE LIABLE FOR INCIDENTAL OR CONSEQUENTIAL DAMAGES.**

---

DO NOT USE INGREDIENT INFORMATION AND/OR INGREDIENT PERCENTAGES IN THIS MSDS AS A PRODUCT SPECIFICATION. FOR PRODUCT SPECIFICATION INFORMATION REFER TO A PRODUCT SPECIFICATION SHEET AND/OR A CERTIFICATE OF ANALYSIS. THESE CAN BE OBTAINED FROM YOUR LOCAL UNIVAR SALES OFFICE.

ALL INFORMATION APPEARING HEREIN IS BASED UPON DATA OBTAINED FROM THE MANUFACTURER AND/OR RECOGNIZED TECHNICAL SOURCES. WHILE THE INFORMATION IS BELIEVED TO BE ACCURATE, UNIVAR MAKES NO REPRESENTATIONS AS TO ITS ACCURACY OR SUFFICIENCY. CONDITIONS OF USE ARE BEYOND UNIVARS CONTROL AND THEREFORE USERS ARE RESPONSIBLE TO VERIFY THIS DATA UNDER THEIR OWN OPERATING CONDITIONS TO DETERMINE WHETHER THE PRODUCT IS SUITABLE FOR THEIR PARTICULAR PURPOSES AND THEY ASSUME ALL RISKS OF THEIR USE, HANDLING, AND DISPOSAL OF THE PRODUCT, OR FROM THE PUBLICATION OR USE OF, OR RELIANCE UPON , INFORMATION CONTAINED HEREIN. THIS INFORMATION RELATES ONLY TO THE PRODUCT DESIGNATED HEREIN, AND DOES NOT RELATE TO ITS USE IN COMBINATION WITH ANY OTHER MATERIAL OR IN ANY OTHER PROCESS.

* * * E N D O F M S D S * * *

*This page intentionally left blank.*

# APPENDIX N

## Emergency Hazardous Materials Containment and Recovery Plan

*This page intentionally left blank.*

# PUBLIC WORKS OPERATIONS
## STANDARD OPERATING PROCEDURES

## 16.0 WATER QUALITY

### 16.1 Personal Protective Equipment (PPE)

PURPOSE: The City of Kent is responsible for providing adequate facilities, equipment, instruments, supervision, and instructions to control safety hazards and comply with applicable state and federal regulations.

SCOPE: The City of Kent is committed to providing a safe working environment for all employees and visitors. As part of this commitment, personal protective equipment (PPE) is provided to help mitigate the hazards inherent to particular tasks or environments at city facilities.

#### 16.1.1 Eye Protection

a) Eye protection shall be worn when performing or observing any of the following or similar tasks:
   - Working with chemicals either in a liquid or solid state, using compressed gas including air
   - Working with corrosive or toxic material
   - Working with infectious or potentially infectious materials
   - Repair of mechanical equipment
   - Milling, sawing, drilling or any type of machining of any material
   - Custodial or grounds keeping activities that reasonably could be injurious to the eye
   - Any other operation that reasonably could be injurious to the eye

b) Safety glasses must be ANSI Z87.1 approved

c) Chemical goggles must be worn when there is a liquid splash, spray or mist hazard.

#### 16.1.2 Hearing Protection

a) Hearing protection shall be worn in areas deemed to have noise levels above limits established by OSHA for the expected exposure frequency.

b) Hearing protection is to be inspected before each use for tears and contamination. If deficiencies are noted, the hearing protector should be cleaned, repaired, or replaced before use.

DRAFT

### 16.1.3 Respiratory Protection

a) Respiratory protection shall be worn to prevent breathing of air contaminated with harmful dusts, fogs, fumes, mists, gases, sprays, or vapors when the issue cannot be eliminated by engineering control measures.
b) Respiratory protection equipment is to be inspected before each use for tears, cracks, contamination and proper fit. If deficiencies are noted, equipment should be repaired or replaced before use.
c) Respiratory protection equipment shall be stored and maintained per Manufactures recommendations.
d) Employees assigned respiratory protection equipment shall complete an annual fit test performed by a certified tester.

DRAFT

# PUBLIC WORKS OPERATIONS
## STANDARD OPERATING PROCEDURES

### 16.0 WATER QUALITY

### 16.2 Chlorine Handling Procedures

PURPOSE: The purpose of this document is to provide standard operating procedures for personnel when working with chlorine gas.

OVERVIEW: Chlorine is a toxic, corrosive gas that can cause severe burns if inhaled or upon skin contact. It is a greenish-yellow nonflammable liquefied compressed gas, packaged in cylinders under its own pressure. Inhalation may cause coughing, choking, nausea, vomiting, headache, dizziness, difficulty breathing, and delayed pulmonary edema, which can be fatal. Chlorine can be detected by its odor below the permissible limit; however, because of olfactory fatigue, odor may not always provide adequate warning of the harmful concentrations of this substance. Chlorine is an oxidizer and will support combustion. Products of combustion are toxic.

#### 16.2.1 Hazard Communication

a) Entrance doors to chlorine storage and chemical feed facilities must be clearly marked, warning of the danger present. Signs should read "DANGER CHLORINE GAS".
b) NFPA signs shall be posted on buildings visible from the street with the code; HEALTH 4, FLAMMABILITY 0, REACTIVITY 0, SPECIAL OXY.
c) "NO SMOKING" shall be posted both outside and inside of chlorine storage rooms.

#### 16.2.2 Material Safety Data Sheets (MSDS)

a) Review material safety data sheets (MSDS) prior to working with chlorine gas. Current MSDS must be posted in or near room containing chlorine gas Cylinder(s).
b) In the event that transportation of chlorine from one site to another is necessary, an MSDS must be located in the vehicle during transport. All other Department of Transportation requirements must also be met (proper tie downs, placards). Review hazardous materials transportation guide prior to the transportation of any hazardous material.

DRAFT

### 16.2.3 Handling

a) No work with chlorine gas will be performed alone. A second person familiar with the dangers and emergency procedures for handling chlorine must be present at all times while operations with chlorine gas are being carried out.
b) Proper personal protection equipment (PPE) should be worn at all times to prevent eye and skin contact (review current MSDS for requirements).
c) Respiratory protection; use NIOSH approved acid gas cartridge (P100) full face respirator for routine work purposes.
d) Use proper exhaust ventilation when working around chlorine gas.
e) Secure cylinder(s) at all times while in use.
f) Follow individual chlorine feed facility change-out procedures

### 16.2.3 Storage

a) Do not exceed maximum chemical storage capacity posted at each facility.
b) Visually inspect cylinder(s) on a routine basis (daily during normal station visit).
c) Do not allow storage temperature to exceed 125 degrees F.
d) Chlorine leak sensors will be located in all chlorine storage rooms with an audible alarm loud enough to alert personnel prior to building entrance. In addition, a red warning light will illuminate above storage room door when leak sensor is activated.
e) Chlorine is extremely reactive. Do not store any items in chlorine storage room not related to chlorine operation. See MSDS for complete list of incompatibility.

### 16.2.4 Emergency Procedures

a) In case of an accidental release of chlorine gas, such as a leaking cylinder or fittings, evacuate the area immediately (moving up wind and to higher ground) and close the door.
b) Implement the emergency spill response plan immediately and call **911**.
c) For first aid procedures (if needed) reference MSDS
d) Contact Water Supervisor as soon as possible.

DRAFT

# PUBLIC WORKS OPERATIONS
## STANDARD OPERATING PROCEDURES

### 16.0 WATER QUALITY

### 16.3 Spill Response Procedures

PURPOSE: To establish guidelines and procedures to follow in the event of a chemical or other spill/release. Should an incident occur, personnel safety is of utmost importance, DO NOT attempt to mitigate or clean-up a spill you are not trained to handle. For chlorine gas release handling procedures, review SOP 16.2

SCOPE: The City of Kent is committed to providing a safe working environment for all personnel and visitors. Prior to working with any hazardous material, personnel should review and be familiar with MSDS for safety precautions, proper PPE selection and accidental release measures.

#### 16.3.1 Definitions

- **Minor Spills**: small quantities (< 300ml) of agents that may be neutralized or readily contained via spill kits located onsite.
- **Medium Spills**: moderate quantities (300ml – 5 liters) of agents that may be contained via spill kits located on site.
- **Large Spills**: Larger quantities (> 5 liters) of agents that are not readily contained via spill kits located on site.

#### 16.3.2 Minor Spills

A) Identify substance spilled and approximate quantity.
B) Stop leak if you can do so without risk.
C) Contain material per MSDS recommendations utilizing spill kits located within the facility or on the service vehicle. Prevent entry into waterways, sewers, basements or confined areas.
D) Clean-up spilled substance per MSDS recommendations. Neutralize, absorb or cover with dry earth, sand or other non-combustible material and transfer to an approved hazardous waste container for disposal. Container should be labeled as hazardous waste and identify spilled material contained within.
E) Decontaminate the surface where spill occurred using mild detergent and water where appropriate.
F) Notify Water Quality or Water Facilities Supervisor of the incident and action taken.
G) Document procedures taken and follow-up with a written report which shall be reviewed by the appropriate Water Supervisor and submitted to the Water Superintendent. In the event of injury, property damage or environmental release, a City of Kent Incident Report must be completed.

DRAFT

### 16.3.3 Medium Spills

A) Identify substance spilled and approximate quantity.
B) Stop leak if you can do so without risk.
C) Contain material per MSDS recommendations utilizing spill kits located within the facility or on the service vehicle. Prevent entry into waterways, sewers, basements or confined areas.
D) Clean-up spilled substance per MSDS recommendations. Absorb material or cover with dry earth, sand or other non-combustible material and transfer to an approved hazardous waste container for disposal. Container should be labeled as hazardous waste and identify spilled material contained within.
E) Decontaminate the surface where spill occurred, using mild detergent and water where appropriate.
F) Notify Water Quality or Water Facilities Supervisor of the incident and action taken.
G) Document procedures taken and follow-up with a written report which shall be reviewed by the appropriate Water Supervisor and submitted to the Water Superintendent. In the event of injury, property damage or environmental release, a City of Kent Incident Report must be completed.

### 16.3.4 Large Spills

In the event of a spill which involves the release of a type or quantity of a chemical that poses an *immediate* risk to health; or involves an uncontrolled fire or explosion:

A) Evacuate the building.
B) Identify substance spilled and approximate quantity.
C) Initiate emergency response – **Call 911** and give details of the incident, including location, types of hazardous materials involved, and whether there is a personal injury. If first aid is necessary, refer to MSDS for proper first aid measures for substance released.
D) Notify Control Center of situation **(253) 856-5611**. A decision must be made whether substance affects water quality or distribution of water, and whether source should be shutdown. Control Center Operator will contact all other relevant local, state and federal agencies (DOH, DOE, EPA, Department of Fish & Wildlife, DOT, etc.) depending on the location and nature of material released. Control Center will also be responsible for contacting Water Supervisor, Water Superintendent and City Environmental Engineer and apprise of the situation.
E) Stop leak and/or contain material if you can do so without risk. Every effort should be made to prevent the spill from entering storm catch basins, water ways, and ground water in the vicinity of wells and springs.

DRAFT

F) Refer to appropriate state agency or environmental engineer for proper clean-up and disposal.
G) Document procedures taken and follow-up with a written report which shall be reviewed by the appropriate Water Supervisor and submitted to the Water Superintendent. In the event of injury, property damage or environmental release, a City of Kent Incident Report must be completed.

### 16.3.5 Emergency Response Contacts

| | |
|---|---|
| Local Emergency Aid | Dial 911 |
| CHEMTREC | 1-800-424-9300 |
| Department of Health | 1-877-481-4901 |
| Department of Ecology | 1-425-649-7000 |
| Environment Protection Agency | 1-800-424-8802 |
| Department of Fish & Wildlife | 1-800-477-6224 |

DRAFT

# PUBLIC WORKS OPERATIONS
## STANDARD OPERATING PROCEDURES

### 16.0 WATER QUALITY

### 16.4 Sodium Fluoride Handling Procedures

PURPOSE: The purpose of this document is to provide standard operating procedures for personnel when handling or working with sodium fluoride.

OVERVIEW: Sodium Fluoride is a toxic, white to off-white crystalline material that can cause severe eye irritation with burns and skin or respiratory irritation. Skin irritation may be delayed. Inhalation of sufficient quantities may cause the swelling and retention of body fluid in the lungs (oedema). Repeated overexposure to fluorides may have long-term health effects.

#### 16.4.1 Hazard Communication

a) Entrance doors to fluoride storage and chemical feed facilities must be clearly Marked, warning of the danger present. Signs should read "DANGER SODIUM FLUORIDE"
b) NFPA signs shall be posted on buildings visible from the street with code; HEALTH 3, FLAMMABILITY 0, REACTIVITY 0.
c) "NO SMOKING" shall be posted both outside and inside of fluoride storage rooms.

#### 16.4.2 Material Safety Data Sheets (MSDS)

a) Review material safety data sheets (MSDS) prior to working with or around sodium fluoride. Current MSDS must be posted in or near room containing sodium fluoride.
b) When transporting sodium fluoride to various treatment sources, an MSDS and hazardous materials transportation guide must be in the vehicle and within operator reach.
c) All other Department of Transportation requirements must be met.

#### 16.4.3 Handling

a) Do not eat, drink, smoke, apply cosmetics or store personal items in work and storage areas.
b) Use proper PPE which includes wearing impervious protective clothing, including boots, gloves, lab coat, apron or coveralls, as appropriate, to prevent skin contact.
b) Respiratory protection; use NIOSH approved full-face air purifying respirator with NIOSH type N100 filters or better.

DRAFT

c) Use proper ventilation when loading saturator's, and be careful not to load too quickly so as to reduce the amount of particulates introduced into the atmosphere.
d) Wash thoroughly after handling, before meals and breaks and before leaving the work area.

### 16.4.4 Storage

a) Do not exceed maximum chemical storage capacity posted at each facility.
b) Store in a cool, dry, well-ventilated area away from incompatible substances, such as acids and oxidizing materials (see MSDS for complete list of incompatibility).
c) Keep material off floor, stored on pallets, and protect from physical damage.
d) Do not store partial bags. When loading a saturator, use an entire bag.
e) Dispose of empty bags appropriately, ensuring that entire contents of bag have been emptied.
f) Storage area should be kept in a clean and orderly condition.

### 16.4.5 Emergency Procedures

a) Ventilate area of leak or spill.
b) Evacuate all personnel from affected area and deny entry to unauthorized or unprotected individuals.
c) Wear appropriate personal protective equipment as specified in section 16.4.3
d) Pick-up and place in a suitable container for reclamation or disposal, using a method that does not generate dust.
e) Do not walk through or otherwise scatter spilled material.
f) For first aid procedures (if needed) reference MSDS.
g) Contact Water Supervisor as soon as possible in the event of a large release.

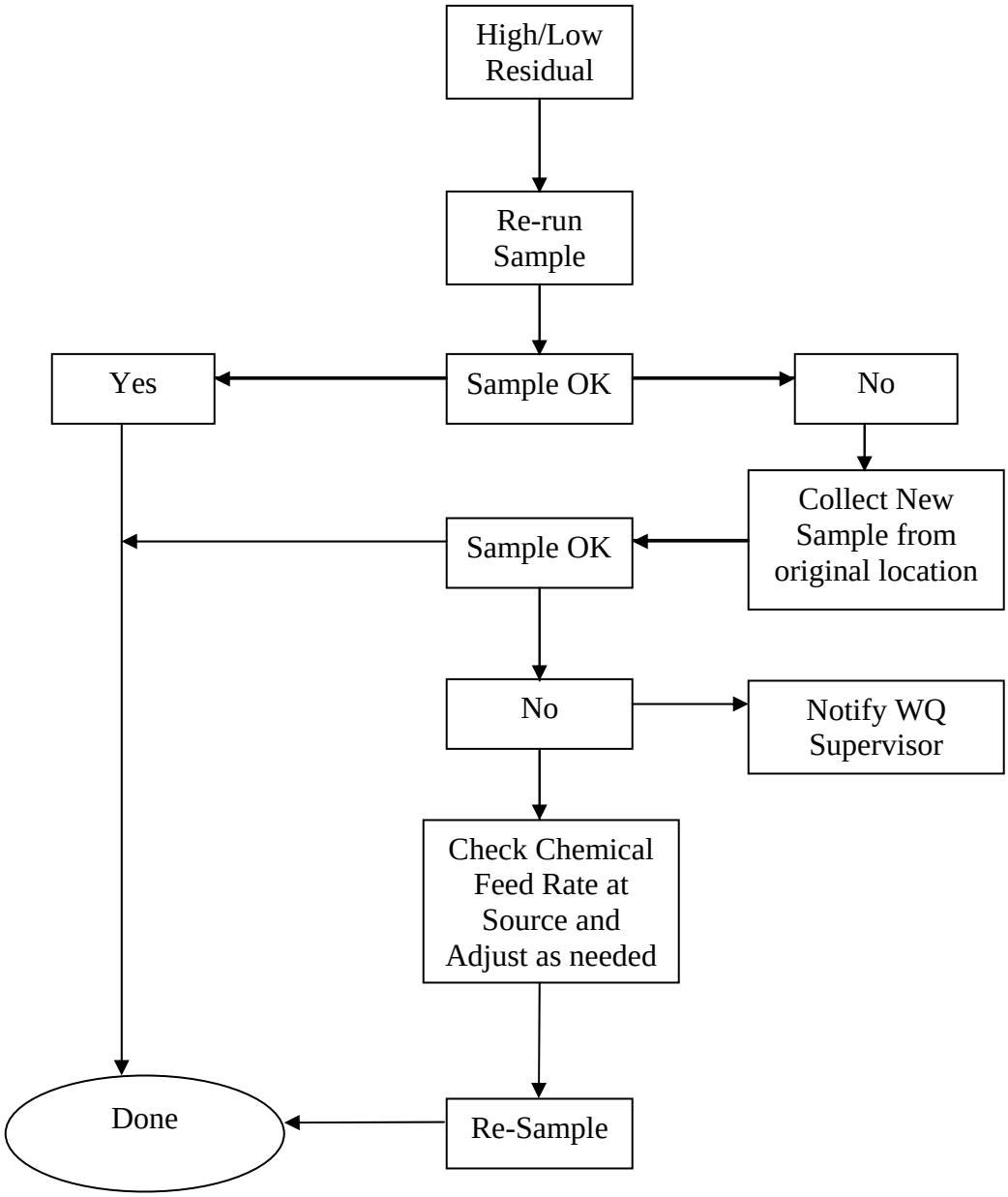
DRAFT

# Water Quality Division

## General Water Sampling Procedures

**Overview:**

This guide is intended to assist Water Quality Personnel with decision making tools for daily water quality sampling (pH, chlorine, fluoride, etc.) in the event of an abnormal parameter (higher or lower than normal result). In the event of an abnormal residual or parameter, please use the following recommendations to help determine the cause and corrective action to be taken to remedy the situation:



# APPENDIX O

## Implementing Agreement

for the

## CITY OF KENT

for

## CLARK SPRINGS WATER SUPPLY SYSTEM HABITAT CONSERVATION PLAN

# IMPLEMENTING AGREEMENT

for the

CITY OF KENT

for

CLARK SPRINGS WATER SUPPLY SYSTEM
HABITAT CONSERVATION PLAN

_____

**CONTENTS**


**1.0 PARTIES ..... 1**

**2.0 RECITALS AND PURPOSES ..... 1**

**2.1 Recitals ..... 1**

**2.2 Purposes ..... 2**

**3.0 DEFINITIONS ..... 2**

**3.1 Terms defined in Endangered Species Act ..... 2**

**3.2 "Changed Circumstances" ..... 2**

**3.3 "Covered activities" ..... 2**

**3.4 "Covered lands" ..... 2**

**3.5 "Covered species" ..... 2**

**3.6 "HCP" ..... 2**

**3.7 "Listed species" ..... 3**

**3.8 "Permit" ..... 3**

**3.9 "Permittee" ..... 3**

**3.10 "Take" ..... 3**

**3.11 "Unforeseen Circumstances" ..... 3**

**3.12 "Unlisted species" ..... 3**

**4.0 OBLIGATIONS OF THE PARTIES ..... 3**

**4.1 Obligations of Permittee ..... 3**

**4.2 Obligations of the Services ..... 3**

**4.2.1 Permit coverage** ..... **3**

**4.2.2 "No surprises" assurances** ..... **3**

**4.3 Interim obligations upon a finding of unforeseen circumstances** ..... **4**

**5.0 INCORPORATION OF HCP** ..... **4**

**6.0 TERM** ..... **4**

**6.1 Initial term** ..... **4**

**6.2 Permit suspension or revocation** ..... **4**

**6.3 Relinquishment of the permit** ..... **4**

**6.3.1 Generally** ..... **4**

**6.3.2 Procedure for relinquishment** ..... **5**

**6.4 Treatment of unlisted species** ..... **5**

**6.5 Extension of the permit** ..... **5**

**7.0 FUNDING** ..... **5**

**8.0 MONITORING AND REPORTING** ..... **5**

**8.1 Planned periodic reports** ..... **5**

**8.2 Other reports** ..... **6**

**8.3 Certification of reports** ..... **6**

**8.4 Monitoring by Services** ..... **6**

**9.0 CHANGED CIRCUMSTANCES** ..... **6**

**9.1 Permittee-initiated response to changed circumstances** ..... **6**

**9.2 Service-initiated response to changed circumstances** ..... **6**

**9.3 Listing of species that are not covered species ..... 6**

**10.0 ADAPTIVE MANAGEMENT ..... 7**

**10.1 Permittee-initiated adaptive management ..... 7**

**10.2 Service-initiated adaptive management ..... 7**

**10.3 Reductions in mitigation ..... 7**

**10.4 No increase in take ..... 7**

**11.0 LAND TRANSACTIONS ..... 7**

**11.1 Acquisition of land by Permittee ..... 7**

**11.2 Disposal of land by Permittee ..... 8**

**12.0 MODIFICATIONS AND AMENDMENTS ..... 8**

**12.1 Minor modifications ..... 8**

**12.2 Amendment of the permit ..... 9**

**13.0 REMEDIES, ENFORCEMENT, AND DISPUTE RESOLUTION ..... 9**

**13.1 In general ..... 9**

**13.2 No monetary damages ..... 9**

**13.3 Injunctive and temporary relief ..... 9**

**13.4 Enforcement authority of the United States ..... 9**

**13.5 Dispute resolution ..... 9**

**14.0 MISCELLANEOUS PROVISIONS ..... 10**

**14.1 No partnership ..... 10**

**14.2 Notices ..... 10**

**14.3 Entire agreement** ..... **11**

**14.4 Elected officials not to benefit** ..... **11**

**14.5 Availability of funds** ..... **11**

**14.6 Duplicate originals** ..... **11**

**14.7 No third-party beneficiaries** ..... **12**

**14.8 Relationship to the ESA and other authorities** ..... **12**

**14.9 References to regulations** ..... **12**

**14.10 Applicable laws** ..... **12**

**14.11 Successors and assigns** ..... **12**

## 1.0 PARTIES

The parties to this Implementing Agreement are the City of Kent, Washington, a municipal corporation ("Permittee"); the United States Fish and Wildlife Service (FWS); and the National Marine Fisheries Service (NMFS). In this agreement, FWS and NMFS are collectively referred to as the "Services."

## 2.0 RECITALS AND PURPOSES

**2.1 Recitals.** The parties have entered into this agreement in consideration of the following facts:

(a) The Clark Springs Water Supply System ("Clark Springs System") has been determined to provide, or potentially provide, habitat for the following listed species:

THREATENED SPECIES

Chinook salmon (*Oncorhynchus tshawytscha*)

Bull trout (*Salvelinus confluentus*)

Steelhead (*Oncorhynchus mykiss*)

(b) The Clark Springs System has also been determined to provide, or potentially provide, habitat for the following unlisted species:

SPECIES OF CONCERN

Coho salmon (*Oncorhynchus kisutch*)

Sockeye salmon (*Oncorhynchus nerka*)

Chum salmon (*Oncorhynchus keta*)

Coastal cutthroat trout (*Oncorhynchus clarki clarki*)

Pacific lamprey (*Lampetra tridentata*)

River lamprey (*Lampetra ayresi*)

(c) Permittee has developed a series of measures, described in the habitat conservation plan (HCP), to minimize and mitigate to the maximum extent practicable the effects of take of covered species incidental to Permittee's covered activities.

**2.2 Purposes.** The purposes of this agreement are:

(a) To ensure implementation of each of the terms of the HCP;

(b) To describe remedies and recourse should any party fail to perform its obligations as set forth in this agreement; and,

(c) To provide assurances to Permittee that as long as the terms of the HCP, the permit, and this agreement are performed, no additional mitigation will be required of Permittee, with respect to covered species, except as provided for in this agreement or required by law.

## 3.0 DEFINITIONS

The following terms as used in this agreement will have the meanings set forth below:

**3.1 Terms defined in Endangered Species Act.** Terms used in this agreement and specifically defined in the Endangered Species Act (ESA) or in regulations adopted by the Services under the ESA have the same meaning as in the ESA and those implementing regulations, unless this agreement expressly provides otherwise.

**3.2 "Changed circumstances"** means changes in circumstances affecting a Covered Species or the geographic area covered by the HCP that can reasonably be anticipated by the permittee and that can reasonably be planned for in the HCP (e.g. the listing of a new species, or a fire or other natural catastrophic event in areas prone to such event.) Changed circumstances and the planned responses to those circumstances are described in Section 2.1.2.3 of the HCP. Changed circumstances are not Unforeseen Circumstances.

**3.3 "Covered activities"** means certain activities carried out by Permittee on covered lands that may result in incidental take of covered species described in Section 1.6 of the HCP.

**3.4 "Covered lands"** means the lands upon which the permit authorizes incidental take of covered species and the lands to which the HCP's conservation and mitigation measures apply . These lands are described in Section 1.5 of the HCP.

**3.5 "Covered species"** means the following species, each of which the HCP addresses in a manner sufficient to meet all of the criteria for issuing an incidental take permit under ESA § 10(a)(1)(B) All covered species are listed in Section 2.1 of this agreement.

**3.6 "HCP"** means the habitat conservation plan prepared by Permittee for the Clark Springs Water Supply System, related property, and activities identified in the HCP.

**3.7 "Listed species"** means a species (including a subspecies, or a distinct population segment of a vertebrate species) that is listed as endangered or threatened under the ESA.

**3.8 "Permit"** means the incidental take permit issued by the Services to Permittee pursuant to Section 10(a)(1)(B) of the ESA for take incidental to covered activities on [*project name/site*], as it may be amended from time to time.

**3.9 "Permittee"** means the City of Kent, Washington, a municipal corporation of the State of Washington.

**3.10 "Unforeseen circumstances"** means changes in circumstances affecting a species or geographic area covered by a conservation plan that could not reasonably have been anticipated by plan developers and the Services on the effective date of this agreement, and that result in a substantial and adverse change in the status of the covered species.

**3.11 "Unlisted species"** means a species (including a subspecies, or a distinct population segment of a vertebrate species) that is not listed as endangered or threatened under the ESA.

## 4.0 OBLIGATIONS OF THE PARTIES

**4.1 Obligations of Permittee.** Permittee will fully and faithfully perform all obligations assigned to it under this agreement, the permit, and the HCP.

**4.2 Obligations of the Services.** Upon execution of this agreement by all parties, and satisfaction of all other applicable legal requirements, the Services will issue Permittee a permit under Section 10(a)(1)(B) of the ESA, authorizing incidental take by Permittee of each listed covered species resulting from covered activities on covered lands.

**4.2.1 Permit coverage.** The permit will identify all covered species. The permit will take effect for listed covered species at the time the permit is issued. Subject to compliance with all other terms of this agreement, the permit will take effect for an unlisted covered species upon the listing of such species.

**4.2.2 "No surprises" assurances.** Provided that Permittee has complied with its obligations under the HCP, this agreement, and the permit, the Services can require Permittee to provide mitigation beyond that provided for in the HCP only under unforeseen circumstances, and only in accordance with the "no surprises" regulations at 50 C.F.R. §§ 17.22(b)(5), 17.32(b)(5), 222.22(g).

**4.3 Interim obligations upon a finding of unforeseen circumstances.** If the Services make a finding of unforeseen circumstances, during the period necessary to determine the nature and location of additional or modified mitigation, Permittee will avoid contributing to appreciably reducing the likelihood of the survival and recovery of the affected species.

## 5.0 INCORPORATION OF HCP

The HCP and each of its provisions are intended to be, and by this reference are, incorporated herein. In the event of any direct contradiction between the terms of this agreement and the HCP, the terms of this agreement will control. In all other cases, the terms of this agreement and the terms of the HCP will be interpreted to be supplementary to each other.

## 6.0 TERM

**6.1 Initial Term.** This agreement and the HCP will become effective on the date that the Services issue the permit. This agreement, the HCP, and the permit will remain in effect for a period of 50 years from issuance of the original permit, except as provided below.

**6.2 Permit suspension or revocation.** The Services may suspend or revoke the permit for cause in accordance with the laws and regulations in force at the time of such suspension or revocation. (See 5 U.S.C. § 558; 50 C.F.R. §§ 13.27 - 13.29, 222.27; 15 C.F.R. Part 904.) Such suspension or revocation may apply to the entire permit, or only to specified covered species, covered lands, or covered activities. In the event of suspension or revocation, Permittee's obligations under this agreement and the HCP will continue until the Services determine that all take of covered species that occurred under the permit has been fully mitigated in accordance with the HCP.

**6.3 Relinquishment of the permit.**

**6.3.1 Generally.** Permittee may relinquish the permit in accordance with the regulations of the Services in force on the date of such relinquishment. (These regulations are currently codified at 50 C.F.R. §§ 13.26, 220.31.) Notwithstanding relinquishment of the permit, Permittee will be required to provide post-relinquishment mitigation for any take of covered species that the Services determine will not have been fully mitigated under the HCP by the time of relinquishment. Permittee's obligations under the HCP and this agreement will continue until the Services notify Permittee that no post-relinquishment mitigation is required, or that all post-relinquishment mitigation required by the Services is completed. Unless the parties agree otherwise, the Services may not require more mitigation than would have been provided if Permittee had carried out the full term of the HCP.

**6.3.2 Procedure for relinquishment.** If Permittee elects to relinquish the permit before expiration of the full term of the HCP, Permittee will provide notice to the Services at least 120 days prior to the planned relinquishment. Such notice will include a status report detailing the nature and amount of take of all covered species, the mitigation provided for those species prior to relinquishment, and the status of Permittee's compliance with all other terms of the HCP. Within 120 days after receiving a notice and status report meeting the requirements of this paragraph, the Services will give notice to Permittee stating whether any post-relinquishment mitigation is required and, if so, the amount and terms of such mitigation, and the basis for the Services' conclusions. If the Services determine that no post-relinquishment mitigation is required, all obligations assumed by the parties under this agreement will terminate upon the Services' issuance of such notice. If Permittee disagrees with the Services' determination, the parties may choose to use the dispute resolution procedures described in Section 13 of this agreement. Permittee will continue to carry out its obligations under the HCP until any such dispute is resolved. If the parties are unable to agree, the Services will have the final authority to determine whether Permittee is required to provide post-relinquishment mitigation.

**6.4 Treatment of unlisted species.** For purposes of paragraph 6.2 and 6.3, unlisted covered species will be treated as though they were listed species in determining the amount of take and the mitigation required.

**6.5 Extension of the permit.** Upon agreement of the parties and compliance with all applicable laws, the permit may be extended beyond its initial term under regulations of the Services in force on the date of such extension. If Permittee desires to extend the permit, it will so notify the Services at least 180 days before the then-current term is scheduled to expire. Extension of the permit constitutes extension of the HCP and this agreement for the same amount of time, subject to any modifications that the Services may require at the time of extension.

## 7.0 FUNDING

Permittee warrants that it has, or shall obtain and shall expend such funds as may be necessary to fulfill its obligations under the HCP. Permittee will promptly notify the Services of any material change in Permittee's financial ability to fulfill its obligations. In addition to providing any such notice, Permittee will provide the Services with a copy of its annual budget for implementation of the HCP each year of the permit, or with such other reasonably available financial information that the parties agree will provide adequate evidence of Permittee’s ability to fulfill its obligations.

## 8.0 MONITORING AND REPORTING

**8.1 Planned periodic reports.** As described in Chapter 5 of the HCP, Permittee will submit periodic reports describing its activities and results of the monitoring program provided for in the HCP.

**8.2 Other reports.** Permittee will provide, within 30 days of being requested by the Services, any additional information in its possession or control related to implementation of the HCP that is requested by the Services for the purpose of assessing whether the terms and conditions of the permit and the HCP, including the HCP's adaptive management plan, are being fully implemented.

**8.3 Certification of reports.** All reports will include the following certification from a responsible company official who supervised or directed preparation of the report:

> I certify that, to the best of my knowledge, after appropriate inquiries of all relevant persons involved in the preparation of this report, the information submitted is true, accurate, and complete.

**8.4 Monitoring by Services**. The Services may conduct inspections and monitoring in connection with the permit in accordance with their regulations. (See 50 C.F.R. §§ 13.47, 220.47.)

## 9.0 CHANGED CIRCUMSTANCES

**9.1 Permittee-initiated response to changed circumstances.** Permittee will give notice to the Services within seven days after learning that any of the changed circumstances listed in Section 2.1.2.3 of the HCP has occurred. As soon as practicable thereafter, but no later than 30 days after learning of the changed circumstances, Permittee will modify its activities in the manner described in Section 2.1.2.3 of the HCP, to the extent necessary to mitigate the effects of the changed circumstances on covered species, and will report to the Services on its actions. Permittee will make such modifications without awaiting notice from the Services.

**9.2 Service-initiated response to changed circumstances.** If the Services determine that changed circumstances have occurred and that Permittee has not responded in accordance with Section 2.1.2.3 of the HCP, the Services will so notify Permittee and will direct Permittee to make the required changes. Within 30 days after receiving such notice, Permittee will make the required changes and report to the Services on its actions. Such changes are provided for in the HCP, and hence do not constitute unforeseen circumstances or require amendment of the permit or HCP.

**9.3 Listing of species that are not covered species.** In the event that a non-covered species that may be affected by covered activities becomes listed under the ESA, the Services will work with Permittee to identify measures necessary to avoid take of, jeopardy to, or adverse modification of the critical habitat of, the species as a result of covered activities. Permittee will implement these measures until the permit is amended to include such species, or until the

Services notify Permittee that such measures are no longer needed to avoid jeopardy to, take of, or adverse modification of the critical habitat of, the non-covered species.

## 10.0 ADAPTIVE MANAGEMENT

**10.1 Permittee-initiated adaptive management.** Permittee will implement the adaptive management provisions in Chapter 5 of the HCP, when changes in management practices are necessary to achieve the HCP's biological objectives, or to respond to monitoring results or new scientific information. Permittee will make such changes without awaiting notice from the Services, and will report to the Services on any actions taken pursuant to this section.

**10.2 Service-initiated adaptive management.** If the Services determine that one or more of the adaptive management provisions in the HCP have been triggered and that Permittee has not changed its management practices in accordance with Chapter 5 of the HCP, the Services will so notify Permittee and will direct Permittee to make the required changes. Within 30 days after receiving such notice, Permittee will make the required changes and report to the Services on its actions. Such changes are provided for in the HCP, and hence do not constitute unforeseen circumstances or require amendment of the permit or HCP, except as provided in this section.

**10.3 Reductions in mitigation.** Permittee will not implement adaptive management changes that may result in less mitigation than provided for covered species under the original terms of the HCP, unless the Services first provide written approval. Permittee may propose any such adaptive management changes by notice to the Services, specifying the adaptive management modifications proposed, the basis for them, including supporting data, and the anticipated effects on covered species, and other environmental impacts. Within 120 days of receiving such a notice, the Services will either approve the proposed adaptive management changes, approve them as modified by the Services, or notify Permittee that the proposed changes constitute permit amendments that must be reviewed under Section 12.2 of this agreement.

**10.4 No increase in take.** This section does not authorize any modifications that would result in an increase in the amount and nature of take, or increase the impacts of take, of covered species beyond that analyzed under the original HCP and any amendments thereto. Any such modification must be reviewed as a permit amendment under Section 12.2 of this agreement.

## 11.0 LAND TRANSACTIONS

**11.1 Acquisition of land by Permittee.** Nothing in this agreement, the HCP, or the permit limits Permittee's right to acquire additional lands. Any lands that may be acquired will not be covered by the permit except upon amendment of the permit as provided in section 12.2 of this agreement.

**11.2 Disposal of land by Permittee**. Permittee's transfer of ownership or control of covered land will require prior approval by the Services and an amendment of the permit in accordance with section 12.2 of this agreement, except that transfers of covered lands may be processed as minor modifications in accordance with section 12.1 of this agreement if:

(a) The land will be transferred to an agency of the federal government and, prior to transfer, the Services have determined that transfer will not compromise the effectiveness of the HCP based on adequate commitments by that agency regarding management of such land;

(b) The land will be transferred to a non-federal entity that has entered into an agreement acceptable to the Services (e.g., an easement held by the state fish and wildlife agency with the Services as third-party beneficiaries) to ensure that the lands will be managed in such a manner and for such duration so as not to compromise the effectiveness of the HCP; or

(c) The Services determine that the amount of land to be transferred will not have a material impact on the ability of the Permittee to comply with the requirements of the HCP and the terms and conditions of the Permit.

## 12.0 MODIFICATIONS AND AMENDMENTS

### 12.1 Minor modifications.

(a) Any party may propose minor modifications to the HCP or this agreement by providing notice to all other parties. Such notice shall include a statement of the reason for the proposed modification and an analysis of its environmental effects, including its effects on operations under the HCP and on covered species. The parties will use best efforts to respond to proposed modifications within 60 days of receipt of such notice. Proposed modifications will become effective upon all other parties' written approval. If, for any reason, a receiving party objects to a proposed modification, it must be processed as an amendment of the permit in accordance with subsection 12.2 of this section. The Services will not propose or approve minor modifications to the HCP or this agreement if the Services determine that such modifications would result in operations under the HCP that are significantly different from those analyzed in connection with the original HCP, adverse effects on the environment that are new or significantly different from those analyzed in connection with the original HCP, or additional take not analyzed in connection with the original HCP.

(b) Minor modifications to the HCP and IA processed pursuant to this subsection may include but are not limited to the following:

(1) corrections of typographic, grammatical, and similar editing errors that do not change the intended meaning;

(2) correction of any maps or exhibits to correct errors in mapping or to reflect previously approved changes in the permit or HCP;

(3) minor changes to survey, monitoring or reporting protocols; and

(4) Other types of modifications that are minor in relation to the HCP, that the Services have analyzed and agreed to.

(c) Any other modifications to the HCP or IA will be processed as amendments of the permit in accordance with subsection 12.2 of this section.

**12.2 Amendment of the Permit.** The permit may be amended in accordance with all applicable legal requirements, including but not limited to the ESA, the National Environmental Policy Act, and the Services' permit regulations. The party proposing the amendment shall provide a statement of the reasons for the amendment and an analysis of its environmental effects, including its effects on operations under the HCP and on covered species.

## 13.0 REMEDIES, ENFORCEMENT, AND DISPUTE RESOLUTION

**13.1 In general.** Except as set forth below, each party shall have all remedies otherwise available to enforce the terms of this agreement, the permit, and the HCP.

**13.2 No monetary damages.** No party shall be liable in damages to any other party or other person for any breach of this agreement, any performance or failure to perform a mandatory or discretionary obligation imposed by this agreement or any other cause of action arising from this agreement.

**13.3 Injunctive and temporary relief.** The parties acknowledge that the covered species are unique and that their loss as species would result in irreparable damage to the environment, and that therefore injunctive and temporary relief may be appropriate to ensure compliance with the terms of this agreement.

**13.4 Enforcement authority of the United States.** Nothing contained in this agreement is intended to limit the authority of the United States government to seek civil or criminal penalties or otherwise fulfill its enforcement responsibilities under the ESA or other applicable law.

**13.5 Dispute resolution.** The parties recognize that disputes concerning implementation of, compliance with, or termination of this agreement, the HCP, and the permit may arise from time to time. The parties agree to work together in good faith to resolve such disputes, using the informal dispute resolution procedures set forth in this section, or such other procedures upon which the parties may later agree. However, if at any time any party determines

that circumstances so warrant, it may seek any available remedy without waiting to complete informal dispute resolution.

**13.5.1 Informal dispute resolution process.** Unless the parties agree upon another dispute resolution process, or unless an aggrieved party has initiated administrative proceedings or suit in federal court as provided in this section, the parties may use the following process to attempt to resolve disputes:

(a) The aggrieved party will notify the other parties of the provision that may have been violated, the basis for contending that a violation has occurred, and the remedies it proposes to correct the alleged violation.

(b) The party alleged to be in violation will have 30 days, or such other time as may be agreed, to respond. During this time it may seek clarification of the information provided in the initial notice. The aggrieved party will use its best efforts to provide any information then available to it that may be responsive to such inquiries.

(c) Within 30 days after such response was provided or was due, representatives of the parties having authority to resolve the dispute will meet and negotiate in good faith toward a solution satisfactory to all parties, or will establish a specific process and timetable to seek such a solution.

(d) If any issues cannot be resolved through such negotiations, the parties will consider non-binding mediation and other alternative dispute resolution processes and, if a dispute resolution process is agreed upon, will make good faith efforts to resolve all remaining issues through that process.

## 14.0 MISCELLANEOUS PROVISIONS

**14.1 No partnership.** Neither this agreement nor the HCP shall make or be deemed to make any party to this agreement the agent for or the partner of any other party.

**14.2 Notices.** Any notice permitted or required by this agreement shall be in writing, delivered personally to the persons listed below, or shall be deemed given five (5) days after deposit in the United States mail, certified and postage prepaid, return receipt requested and addressed as follows, or at such other address as any party may from time to time specify to the other parties in writing. Notices may be delivered by facsimile or other electronic means, provided that they are also delivered personally or by certified mail. Notices shall be transmitted so that they are received within the specified deadlines.

Assistant Regional Director
United States Fish and Wildlife Service

911 N.E. 11th Ave.
Portland, Oregon 97232-4181
Telephone: 503-231-6159
Telefax: 503-231-2019

Regional Administrator
National Marine Fisheries Service
7600 Sand Point Way N.E.
Seattle, Washington 98115-0070
Telephone: 206-526-6150
Telefax: 206-526-6426

Public Works Director
City of Kent
400 West Gowe Street
Kent, WA 98032
Telephone: 253-856-5500
Telefax: 253-856-6500

**14.3 Entire agreement.** This agreement, together with the HCP and the permit, constitutes the entire agreement among the parties. It supersedes any and all other agreements, either oral or in writing, among the parties with respect to the subject matter hereof and contains all of the covenants and agreements among them with respect to said matters, and each party acknowledges that no representation, inducement, promise or agreement, oral or otherwise, has been made by any other party or anyone acting on behalf of any other party that is not embodied herein.

**14.4 Elected officials not to benefit.** No member of or delegate to Congress shall be entitled to any share or part of this agreement, or to any benefit that may arise from it.

**14.5 Availability of funds.** Implementation of this agreement and the HCP by the Services is subject to the requirements of the Anti-Deficiency Act and the availability of appropriated funds. Nothing in this agreement will be construed by the parties to require the obligation, appropriation, or expenditure of any money from the U.S. Treasury. The parties acknowledge that the Services will not be required under this agreement to expend any federal agency's appropriated funds unless and until an authorized official of that agency affirmatively acts to commit to such expenditures as evidenced in writing.

**14.6 Duplicate originals.** This agreement may be executed in any number of duplicate originals. A complete original of this agreement shall be maintained in the official records of each of the parties hereto.

**14.7 No third-party beneficiaries.** Without limiting the applicability of rights granted to the public pursuant to the ESA or other federal law, this agreement shall not create any right or interest in the public, or any member thereof, as a third-party beneficiary hereof, nor shall it authorize anyone not a party to this agreement to maintain a suit for personal injuries or damages pursuant to the provisions of this agreement. The duties, obligations, and responsibilities of the parties to this agreement with respect to third parties shall remain as imposed under existing law.

**14.8 Relationship to the ESA and other authorities.** The terms of this agreement shall be governed by and construed in accordance with the ESA and applicable federal law. In particular, nothing in this agreement is intended to limit the authority of the Services to seek penalties or otherwise fulfill their responsibilities under the ESA. Moreover, nothing in this agreement is intended to limit or diminish the legal obligations and responsibilities of the Services as agencies of the federal government. Nothing in this agreement will limit the right or obligation of any federal agency to engage in consultation required under Section 7 of the ESA or other federal law; however, it is intended that the rights and obligations of Permittee under the HCP and this agreement will be considered in any consultation affecting Permittee's use of the covered lands.

**14.9 References to regulations.** Any reference in this agreement, the HCP, or the permit to any regulation or rule of the Services shall be deemed to be a reference to such regulation or rule in existence at the time an action is taken.

**14.10 Applicable laws.** All activities undertaken pursuant to this agreement, the HCP, or the permit must be in compliance with all applicable state and federal laws and regulations.

**14.11 Successors and assigns.** This agreement and each of its covenants and conditions shall be binding on and shall inure to the benefit of the parties and their respective successors and assigns. Assignment or other transfer of the permit shall be governed by the Services' regulations.

IN WITNESS WHEREOF, THE PARTIES HERETO have executed this Implementing Agreement to be in effect as of the date that the Services issue the permit.

BY _____ Date _____

Regional Director
United States Fish and Wildlife Service
Portland, Oregon

BY _____ Date _____

Regional Administrator
National Marine Fisheries Service
Seattle, Washington

BY _____ Date _____

Mayor
City of Kent, Washington