U.S. Fish & Wildlife Service

Oxon Run, Washington, D.C. Stream Restoration Concept Development

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OXON RUN 30% DESIGN SUBMITTAL
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OXON RUN STREAM RESTORATION CONCEPT DEVELOPMENT

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EXECUTIVE SUMMARY

A. INTRODUCTION

In 2002, the District of Columbia (District), Department of Health, Environmental Health Administration (DOH) and the U.S. Fish and Wildlife Service (Service) - Chesapeake Bay Field Office (CBFO) implemented a partnership agreement (Agreement 1902-0172) to pursue restoration efforts for the Potomac River, the Anacostia River, and their tributaries. As one task under this agreement, the CBFO Stream Habitat Assessment and Restoration Program (SHARP) conducted a detailed assessment of the Oxon Run watershed. Portions of the Oxon Run watershed lie within the District south of the Anacostia River and adjacent to the border with Prince George's County, Maryland (Brown et al. 2003). The remainder of the Oxon Run watershed lies within Prince George's County. The assessment report recommended that the District undertake a comprehensive stream restoration of the 15,100 feet long main stem of Oxon Run lying within the District boundaries (Figure 1).

DOH and the Service agreed to prepare conceptual stream restoration design plans for two representative reaches as a preliminary task in the implementation of a stream restoration plan. The ultimate intent is to construct stream restoration for the entire length of Oxon Run in the District. Development of concept plans for the representative reaches are pilot studies that will provide information for developing full design plans for all of Oxon Run. Preparation of the concept plans for the two representative reaches provide detailed information on the scale of restoration efforts required for the entire length of Oxon Run. The first representative reach consists of approximately 2,000 linear feet of an unstable, meandering stream. The second representative reach consists of approximately 2,000 linear feet of a concrete-lined trapezoidal channel.

The purpose of this report is to document development of the concept plans for the two representative reaches. Details are provided on detailed site analysis, plan development, and discussions with other involved agencies and partners. The report presents analyses of site geomorphology, bankfull hydrology, and floodplain management. Alternative stream restoration concepts are presented for each of the study reaches along with the reasoning used to shape the proposed concept plans.

B. OXON RUN MAIN STEM LOCATION AND FEATURES

Oxon Run is a tributary of the Potomac River and secondary tributary to the Chesapeake Bay. The main stem of Oxon Run originates in Prince George's County, Maryland, and flows for approximately four miles before crossing into the District. After crossing the District boundary, the Oxon Run main stem flows for three miles along the southeast border of the District. The portion of Oxon Run extending from 13th Street to South Capitol Street (a length of 7,920 feet) has been replaced with a concrete channel. Oxon Run returns to an unlined stream below South Capitol Street and flows for approximately 2,040 feet before crossing back into Prince George's County.

A concrete drop-structure is located at the Prince George's County line that creates a barrier to upstream fish passage. The drop structure is part of the U.S. Army Corps of Engineers (Corps) flood protection works for the community of Forest Heights. Below

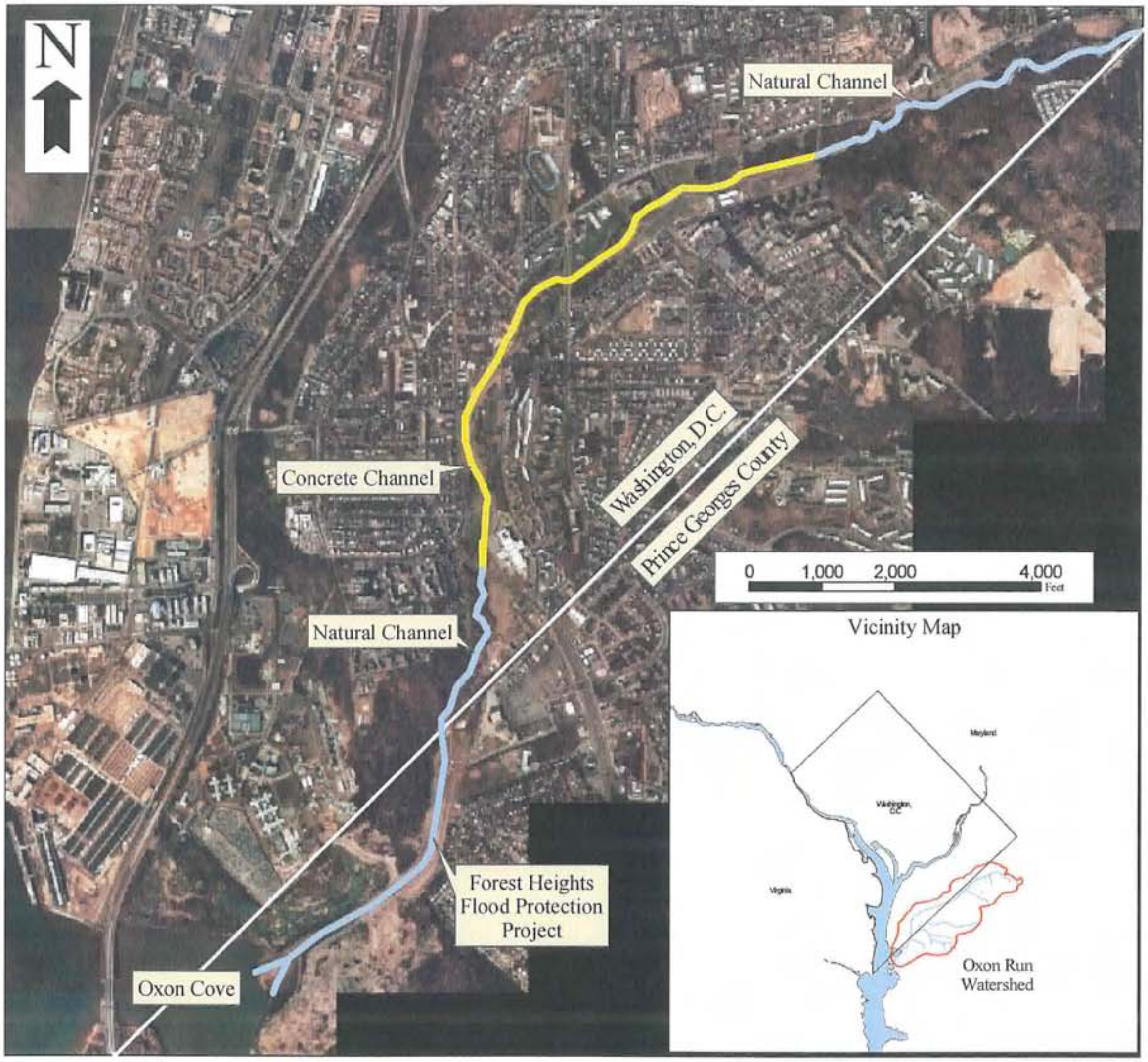

Figure 1: Oxon Run Stream Restoration - General Features

the drop structure, Oxon Run flows for approximately one mile, entering Oxon Cove and then crossing back into the District before its confluence with the Potomac River (Figure 1).

C. OXON RUN WATERSHED ASSESSMENT

1. Assessment Objectives and Methodology

The Service completed a detailed watershed assessment (Oxon Run Assessment) of Oxon Run in 2003 (Brown et al. 2003) under agreement with the District. Watershed assessment work tasks included:

- Determining the relationship between watershed landscape activities and stream processes in Oxon Run;
- Determining Rosgen stream types and stability conditions;

- Prioritizing restoration needs;
- Developing watershed restoration recommendations; and
- Developing preliminary design criteria for stream restoration.

As part of the Oxon Run Assessment, the Service analyzed land use/land cover patterns and development in the watershed using historical maps and aerial photos, and reviewed water quality and biological assessment data. The assessment covered the entire Oxon Run watershed including portions of the watershed lying within Prince George's County, Maryland. The Service also performed a detailed stream assessment of the portions of Oxon Run within the District using stream classification and assessment methodology developed by Rosgen (1996).

2. Findings

The Oxon Run Assessment concluded that overall watershed and stream conditions in Oxon Run are poor. The Oxon Run watershed is highly urbanized; approximately 33 percent of the land cover is impervious surface. Development has altered the rainfall-runoff regime. Runoff arrives at the stream quickly via overland flow on impervious areas collected by storm drains, rather than slowly by overland flow on pervious surfaces that allows losses to infiltration and depression storage. Virtually all of the streams in the Oxon Run watershed are unstable, and have poor potential for recovery without restoration. As the unstable reaches incise and migrate laterally, extensive streambank erosion occurs. Streambank erosion produces an estimated 18,000 tons of sediment per year. Approximately six percent of this sediment comes from the portion of Oxon Run within the District. Aquatic habitat is poor, in large part due to marginal bed feature development, and the lack of defined pool-riffle sequences. In many locations, there are obstacles to fish passage, such as utility line crossings, pipes, and culverts. Streams in the watershed are rated as poor or very poor based on macroinvertebrate and fish rapid bioassessment procedures (RBPs) conducted by the Maryland Biological Stream Survey (MBSS) and other agencies. Water quality is poor, with degradation caused by pollutants from stormwater runoff, sanitary sewer leaks, and trash.

3. Restoration Recommendations

The Oxon Run Assessment made specific recommendations for addressing problems in the Oxon Run watershed that involved improving stream stability, water quality, sanitary and storm sewer infrastructure, and riparian habitat and riparian buffers. Achieving complete restoration of the Oxon Run Watershed will require a concerted effort by the District as well as a wide variety of other groups that include local governments, sewer authorities, state and federal agencies, and the general public. A key element of the restoration plan was the recommendation that the District restore the main stem of Oxon Run.

D. CONCEPT DESIGN

1. Representative Reaches

Undertaking the complete restoration of Oxon Run is a major effort. As a first step in the process, the DOH and the Service agreed to prepare 30 percent completion stream restoration concept plans for two representative reaches in the Oxon Run main stem. The concept plans are pilot studies for developing full design and restoration of Oxon Run within the District. The intent is for the 30 percent concept plans to provide detailed information on the scale of the restoration effort required to restore stream stability, the extent of stream and floodplain alternations, and better information on the costs required to construct the project. Development of the 30 percent concept plans also identifies opportunities for combining the stream restoration work with other watershed restoration efforts and community improvements. The plans will not be used to restore individual reaches of Oxon Run.

The Oxon Run Assessment divided the main stem of Oxon Run within the District into two broad categories: natural (unlined) stream reaches and concrete channel reaches. The natural streams have been altered to varying degrees either directly by straightening or enlargement for flood control purposes; or indirectly by urbanization, increases in the frequency and duration of stormflow, or floodplain alternations and filling. To evaluate the restoration efforts required for natural and concrete channels, the Service developed concept plans for a representative natural reach and a representative portion of the concrete channel.

2. Representative Reach for Natural Streams - Oxon Run Reach 2

Oxon Run Reach 2 (OR-2) was selected to represent natural (unlined) stream reaches. During the Oxon Run Assessment, the portion of Oxon Run extending from the District line to 13th Street (start of concrete section) was divided into eight reaches (Reaches OR-1 to OR-8). Stream characteristics within each reach are uniform. Reach boundaries represent the location where general stream characteristics change. Reach OR-2 is a 1,850-foot long reach located 460 feet downstream of where Oxon Run crosses into the District (Figure 2). Reach OR-2 is typical of Oxon Run reaches that meander. Reach OR-2 was classified as a Rosgen B4c stream type indicating that the stream reach is moderately entrenched, has a moderate bankfull width to bankfull mean depth ratio, and has moderate stream sinuosity.

3. Representative Reach for Lined Channels - Oxon Run Reach 9B

Oxon Run Reach 9 (OR-9) is the 7,920-foot long concrete channel section of Oxon Run. A portion of Oxon Run Reach 9 that extends 2,520 feet from Wheeler Road to 4th Street was selected for the concept design[1]. The subsection (Reach OR-9B) is typical of the entire concrete channel reach. While the concrete channel is located in open park land, there are design issues created by the presence of sanitary sewers near the existing

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[1] For the purposes of this report, the subsection of Oxon Run Reach 9 (OR-9) is referred to as Oxon Run Reach 9B (OR-9B).

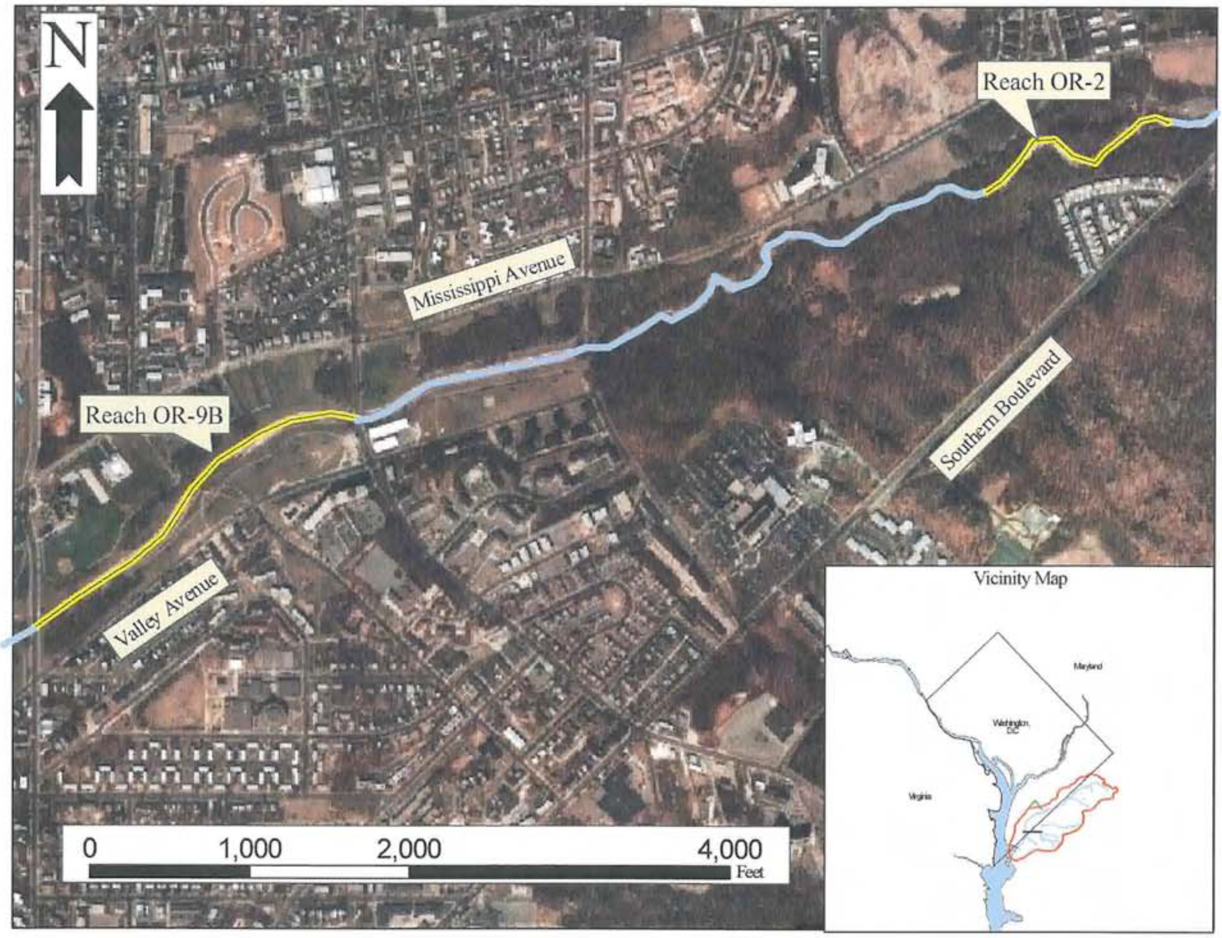

Figure 2: Oxon Run Concept Reaches

concrete channel, and buildings and recreation facilities located within the fringes of the 100-year return period floodplain.

E. Restoration Objectives

Prior to undertaking development of a restoration plan, it is important to clearly identify objectives for a potential stream restoration project. Stream restoration objectives should be set with an understanding of the source of stream problems, the constraints inherent within a given watershed and stream system, and of the potential for remedial success. During the Oxon Run Assessment, the Service determined cause-and-effect relationships and identified the types of stream configurations and adjustments that have the best potential to remedy identified stream problems. Working with DOH, the Service developed an initial set of restoration objectives based on the needs for stream, watershed, and habitat improvement.

DOH and the Service met with other agencies involved in management of the lands and infrastructure where the two representative reaches of Oxon Run are located to review restoration objectives and to obtain input on their objectives. The Service and DOH held discussions with:

- The National Park Service (NPS) which owns and manages the land where Reach OR-2 is located.
- The District of Columbia Department of Parks and Recreation (DPR) which manages the lands where the concrete-lined channel section of Oxon Run is located.
- District of Columbia Water and Sewer Authority (WASA) which operates and maintains sanitary sewers and storm sewers in and around both representative reaches.

The Service revised or expanded objectives in response to comments by involved agencies. A complete listing of restoration objectives is provided in Appendix A.

The key restoration objective is to restore a natural stable stream to Oxon Run using natural channel design principles. Other objectives involve integrating the stream with park land uses. The optimal concept plan satisfies all objectives. Specific details on how the concept plans address these objectives are provided in the discussions below on development of concept plans.

Specific, numeric goals for the restoration will be identified in subsequent design phases. Specific goals might include numeric targets for water quality improvements (*e.g.*, temperature, dissolved oxygen) or habitat (*e.g.*, volume of pools).

F. Design Methodology

1. Natural Channel Design Methodology

The Service developed concept plans for the two alternatives using natural channel design methodology. The Service developed shape parameters for the restored stream channel by scaling geomorphic channel parameters for stable stream channels to the design stream. Design parameters include stream width at bankfull discharge, stream slope, cross section area-depth relationships, the distribution and shapes of pools and riffles, etc. The Service used bankfull discharge and bankfull mean depth to scale geomorphic stream shape parameters from stable reaches to the representative reaches. More details on the implementation of the natural channel design are presented in Section I.

2. Topographic Survey

As part of field investigations, the Service prepared field-run topographic surveys of both representative reaches. The survey included detailed mapping of the limits and depths of the stream, adjacent floodplains, and any features near the stream corridor such as roadways, fences, bridges, and buildings. The Service entered the survey data into the Terramodel® CADD package (Trimble 2004) to create digital terrain models (DTM) of the two representative reaches. The Service developed stream restoration concept plans in Terramodel®.

3. Hydraulic Analysis

The Service prepared hydraulic analyses of existing conditions and proposed conditions after implementation of the stream restoration concepts using the Corps HEC-RAS hydraulic model (Hydrologic Engineering Center 2002). HEC-RAS is a standard tool for evaluating water surface elevations for floodplain management. The Service compared hydraulic results to evaluate the effects of alternate concept plans on flood elevations for major floods.

4. Cost Estimates

The Service developed concept level cost estimates for the two representative reaches. The Service estimated unit costs for standard construction items using bid tabulations for stream restoration projects recently bid by for projects in Washington, DC and metropolitan areas of Maryland.

G. Design Results

1. 30 Percent Design Plans

The Service developed detailed concept plans approximating a 30 percent completion design for each of the two restoration reaches. The plans consist of site grading for implementation of the natural channel design, horizontal and vertical profiles for the restored streams, location and sizing of natural channel structures, and earthwork analyses to determine the volumes of cut and fill.

The Service evaluated several alternatives for each reach. One set of 30 percent design completion concept plans was fully developed for each representative reach. Discussions of the factors influencing and controlling design alternatives are provided in Sections II and III. Alternative concepts for each site are discussed also.

2. Concept Descriptions

Reach OR-2

Reach OR-2 is currently a meandering stream reach. Problems identified during the Oxon Run Assessment include tight meander curves, stream entrenchment, lack of pools, shallow base flow in an over-widened low-flow channel, and high, steep eroding banks. The reach flows through an area of mature forests that NPS rates as a valuable interior dwelling habitat for neotropical birds.

In keeping with NPS objectives to limit disturbance in the mature forest stands, the alignment (planform) for the proposed stream restoration generally stays within the limits of the current active channel. The Service made minor adjustments to the planform to improve overall stream stability and to improve pool-riffle spacing. The stream restoration plan decreases average bankfull width from 51 feet to 35 feet and increases average bankfull stream depth from 1.8 feet to 2.37 feet. Stream sinuosity increases from 1.17 to 1.20 as stream length increases from 1,847 feet to 1,899 feet. The restoration plan reduces stream entrenchment and provides greater access to the floodplain for flows above bankfull. The concept plan calls for the installation of rock cross-vanes and J-hooks to form pools and to provide interim bank protection after construction.

Reach OR-9B

The Service developed concept designs for the portion of Reach OR-9 that extends from Wheeler Road to 4th Street (OR-9B). Oxon Run flows through a 2,520-foot long concrete lined channel in this section. The concrete channel is generally straight except for three broad curves. The land surrounding the channel is generally open grassland with several patches of mature trees. Two schools, a swimming pool, and a tennis center are located on the north side of the channel along Mississippi Avenue. It appears that fill was placed on both sides of the channel near Wheeler Road creating a restricted floodplain.

The proposed concept calls for removing the concrete channel and installing a natural stream. The concept plans include installing a natural stream with a length of 2,660 feet, a bankfull width of 35 feet, and a bankfull mean depth of 2.34 feet. The plan includes significant excavation in the fill areas near Wheeler Road to reduce flood elevations for 100-year floods.

H. FINDINGS

1. Cost Estimates

The Service developed concept level cost estimates for each restoration reach and used the estimates to extrapolate total costs for restoring the Oxon Run main stem within the District.

Estimated costs for construction of stream restoration for Reach OR-2 are $534,400 or $230 per linear foot. Design and construction management costs are $130,000 or $72 per linear foot. Stormwater management retrofit for four storm sewers in Reach OR-2 is estimated to cost $81,700 for construction and $24,600 for design and construction management. Total stormwater retrofit costs are $106,300 or about $26,600 per storm sewer.

Estimated costs for construction of stream restoration for Reach OR-9B are $807,800 or $303 per linear foot. Design and construction management costs are $232,600 or $87 per linear foot. Removal of the concrete channel is estimated to cost $224,000 or $84 per linear foot. Stormwater management retrofit for five storm sewers is estimated to cost $206,500 for construction and $62,000 for design and construction management. Total stormwater retrofit costs are $268,500 or about $53,700 per storm sewer.

Cost estimates are higher for Reach OR-9B than for Reach OR-2 due to extra excavation costs to remove fill from the floodplain, costs for removing the concrete channel, use of larger stormwater ponds, and construction of a deeper pond.

Total estimated costs for construction of stream restoration for the main stem of Oxon Run within the District are $5,489,000. Engineering and construction management costs are $1,399,000. Total costs for stream restoration are $6,888,000. This does/does not include removal of the drop structure at the Forest Heights Flood Protection Project or costs for Oxon Run Park redevelopment features that are not directly related to stream restoration.

Stormwater retrofit costs for the Oxon Run main stem are roughly estimated to cost $1,094,000. Cost estimates for stormwater retrofit are rough because costs vary significantly with individual site conditions and the type of retrofits employed at each site.

Unit costs for the estimates are from stream restoration projects in the Washington, DC metropolitan area and reflect standard construction bidding and management methods. The Service believes that it will be possible to reduce unit costs through alternate contracting, construction management, and inspection procedures.

2. Further Investigation Needs

The Service identified further investigation needs during preparation of the concept plans. The following work will improve the reliability of stream restoration designs and reduce project costs:

- Conduct a program to develop sediment transport and discharge rating curves for Oxon Run in two locations. This information will be used to refine stream roughness estimates, to validate sediment transport rates, and to allow better prediction of sediment loads.
- While the Service did not locate a stream reference reach in the southeast portion of the District during the assessment phase, we recommend further investigation of stable urban streams with good habitat. The survey information from these streams will refine methodology for developing stream restoration design parameters in highly urban areas.
- Obtain digital orthophotos with contours for the Oxon Run main stem within the District encompassing the 100-year floodplain and to the limits of park boundaries. This data may be available from others.
- Establish or locate existing horizontal and vertical bench marks for use during survey and construction. Bench marks available from District Surveyor are inadequate or have been destroyed. WASA may be able to provide bench marks.

3. Recommendations for Oxon Run Restoration

The two concept plans demonstrate the feasibility of restoring Oxon Run. The next logical steps in the process of implementing the restoration are:

- Complete integrated concept designs for the remaining portions of the Oxon Run main stem within the District.
- Complete final designs.
- Conduct sediment sampling and discharge measurement activities for Oxon Run to develop calibrated rating curves and to validate TMDL.
- Coordinate design efforts with DPR and WASA.
- Hold a public meeting with all interested groups, including the public.
- Restore Prince George's County portion of Oxon Run.

I. RESTORATION DESIGN METHODOLOGY

A. INTRODUCTION

This section describes the technical procedures used to develop concept plans for the two representative reaches of Oxon Run. Detailed descriptions of particular issues associated with each project site are presented in Sections III and IV. The first major work effort was to develop geomorphic design parameters for the restored reaches so that the streams could be designed using natural channel design methodology. Subsequent tasks involved developing surveys and mapping, preparing grading plans and calculations, analyzing flow hydraulics for the concepts, evaluating compliance with floodplain management regulations, and developing cost estimates.

B. DEVELOPMENT OF GEOMORPHIC DESIGN PARAMETERS

1. Natural Channel Design Methodology

The Service developed stream restoration design concepts for the two representative reaches using natural channel design methodology. The goal of the natural channel design approach is to adjust stream planform, cross-section, and profile such that restored streams accommodate their regimes of flows and sediment supply without creating erosion or deposition impacts within, upstream, or downstream of restored reaches. Natural channel design methodology employs geomorphic measurements from stable, natural streams as a template for designing the restored stream. Measurements from stable streams are scaled by ratios of bankfull mean depth, bankfull width, and bankfull discharge to develop planform, cross section, and vertical profiles for restored streams.

2. Stream Assessment and Classification

The Service conducted detailed stream assessments of the Oxon Run main stem during the Oxon Run Assessment. Detailed geomorphic measurements included determining stream sinuosity, bankfull width, bankfull mean depth, floodprone width, stream substrate characteristics, stream slope, and discharge characteristics.

The Service used geomorphic measurements to classify streams with the Rosgen Stream Classification System (Rosgen 1996). Rosgen stream classification assigns a stream to one of nine "stream types" referenced by a letter (*e.g.*, A, B, C…). The letters reflect streams with similar grouping of geomorphic ratios rather than a quality grade. The ratios used to determine the classifications are bankfull width to bankfull mean depth (width/depth ratio), stream sinuosity (ratio of stream length to down-valley length), and entrenchment ratio (ratio of the stream width at twice bankfull mean depth to the bankfull width). Further refinements in stream classification are made by incorporating assessments of the dominant stream substrate and stream slope.

Stream stability, flow characteristics, and habitat potential may be inferred from stream type because of the geomorphic relationships implicit in the defining geomorphic variables. Stream classification of Oxon Run allowed the Service to identify unstable streams and the processes generating instabilities. The Service identified departures in conditions at Oxon Run from reference conditions, which allowed assessment of the degree of stream instability.

Urbanization of the watershed and stream alteration created stream instabilities in the natural stream sections of Oxon Run. The majority of the Oxon Run reaches are incised and over-widened. Oxon Run does not have access to its floodplain which results in increased sediment transport and bank erosion. Habitat has been lost because the stream does not maintain pools. Stream widening and loss of baseflow caused further habitat degradation due to reduced depths of flow.

Appendix B contains a detailed listing of the morphological parameters that the Service obtained from survey of Oxon Run Reaches OR-2 and OR-10, which are representative of reaches where natural stream sections meander.

3. Bankfull Discharge

Purpose of Bankfull Discharge

Bankfull discharge is the maximum discharge that a stream can convey before flow starts to exceed the stream capacity and flow onto a stream's floodplain. During field investigations, the Service identifies the stage at which bankfull discharge occurs at multiple locations along a study reach. Then, the Service conducts cross section surveys at representative riffles. Analysis is made of riffle cross sections to identify the bankfull mean depth, bankfull cross section area, and bankfull width.

Bankfull discharge characterizes the range of discharges that is effective in shaping and maintaining a stream. Over time, geomorphic processes adjust the stream capacity and shape to accommodate the bankfull discharge within the stream. Many important stream morphological features (*e.g.,* bankfull width, drainage area, etc.) are strongly correlated to bankfull discharge. Thus, bankfull discharge is used in natural channel design procedures as a scale factor to convert morphological parameters from a stable reach of one size to a disturbed reach of another size.

Methodology

The opportunities to establish bankfull discharge through physical measurements of streamflow are often elusive, so the value of bankfull discharge is often estimated through indirect methods. The Service uses regional stream relationships between drainage area and bankfull discharge, such as developed by McCandless 2003, to develop broad estimates of bankfull discharge. For Oxon Run, the estimates were further refined by comparison to bankfull discharge measured at the United States Geological Survey (USGS) Watts Branch stream gage[2], and through field measurements of hydraulic properties in Oxon Run and estimates of channel roughness.

The Service identified existing Oxon Run bankfull stage and related hydraulic shape parameters (cross section area, mean depth, hydraulic radius, etc.) through stream assessment and cross section surveys. The energy slope for bankfull discharge is

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[2] USGS Gage 01651800, Watts Branch at Washington, D.C., LOCATION.--Lat 38°54'04.0", Long 76°56'31.9", District of Columbia, Hydrologic Unit 02070010, on right bank 5 ft downstream from footbridge, 200 ft upstream from Minnesota Ave., and 1.0 mi upstream from mouth.

assumed to be roughly equivalent to the longitudinal slope of bankfull indicators along a homogenous reach. The Service employs several methods to estimate channel roughness and bankfull flow velocity from channel substrate characteristics and other physical channel features.

The Service made final estimates of bankfull discharge by comparing discharge estimates developed by alternate methods, evaluating the consistency of estimates along a reach, and consideration of the appropriateness of alternate methods for the particular site application. The following paragraphs provide specific details on development of bankfull discharge estimates.

Field Determination of Bankfull Stage

During the Oxon Run Assessment, the Service identified bankfull stages using physical indicators of bankfull stage described by McCandless and Everett (2002). Indicators found to be significant in Maryland are depicted in Figure 3 and described below:

- **Floodplain break:** a discrete transition from near vertical to near horizontal; used on straight reaches or on bends lacking point bars. In some cases, (where the stream in not entrenched or incised) the floodplain break may also be the top of bank.
- **Inflection point:** where the transition from near vertical bank to near horizontal floodplain is not relatively discrete, but instead occurs over a transitional zone often composed of one or more obtuse slope breaks over a vertical distance of several tenths of a foot, the inflection point is the lowest identifiable break in slope.
- **Scour line:** a wear mark on a vertical bank, or a discrete break in slope (acute or obtuse) of the channel bank, distinguished from an inflection point by being

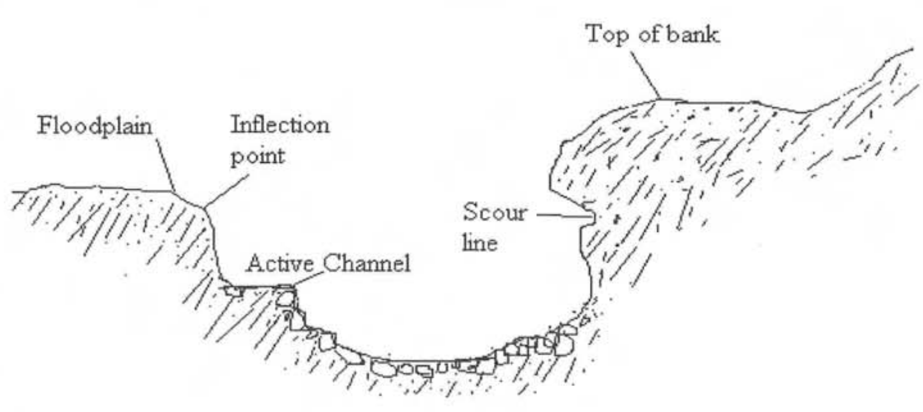


Figure 3: Typical bankfull indicators

further down from the top of bank.

- **Depositional bench:** the flat surface, or highest elevation, of a lateral depositional surface other than a point bar. This may also be referred to as the active channel.
- **Point bar:** the transition point from inclining point bar surface to horizontal floodplain surface.

Multiple Field Indicators

The Service assessed two other streams, Watts Branch (Eng 2002) and Hickey Run (Starr et al., under preparation) within the District at about the same time that the Service prepared the Oxon Run Assessment. All three streams are located in the south east area of the District and have similar land use and land cover. Stream assessments identified three sets of consistent geomorphic features in all three streams at differing elevations (Starr et al., 2003). Geomorphic features in Watts Branch and Hickey Run are similar. Geomorphic features in Oxon Run are sometimes different in form (but not in location relative to stream cross section). Features in Oxon Run are more likely to be formed by sediment deposition processes than features in Hickey Run and Watts Branch. Oxon Run has much larger entrenchment ratios[3] than Watts Branch and Hickey Run. A higher entrenchment ratio implies greater access of a stream to its floodplain. Because Oxon Run has greater floodplain access, shear stresses are reduced during above bankfull flow events. Higher shear stresses in Watts Branch and Hickey Run tend to strip the channel of depositional features.

The three sets of geomorphic features have the following characteristics:

- **Low geomorphic feature:** The low geomorphic feature is typically the inflection point above the active channel. In the Upper Reach of Watts Branch, the low geomorphic feature is a slope break above the inflection point. The Upper Reach of Watts Branch is more entrenched than other streams, which may explain the difference. In Oxon Run, the low geomorphic feature is the first inflection point above the low flow channel; it corresponds to the top of lateral (instream) gravel bars; and it encompasses areas of active sediment transport.
- **Mid geomorphic feature:** The mid geomorphic feature typically consists of the first dominant slope break located above the low geomorphic feature. At Oxon Run, the mid geomorphic feature is at the first slope break above the inflection point. The mid geomorphic feature is consistent through all Oxon Run natural stream reaches.
- **High geomorphic feature:** The high geomorphic feature varies between sites. Generally, the high geomorphic feature consists of a slope break above the middle indicator or is associated with a flat above the mid geomorphic feature. At Watts Branch, the high geomorphic feature is associated with a dominant slope break

[3] Entrenchment ratio is the ratio between channel width at a stage equivalent to twice maximum bankfull depth above the channel thalweg to the channel width at bankfull stage. The ratio expresses the growth in channel area above bankfull stage. A higher entrenchment ratio implies that a stream channel has greater access to its floodplain at stages above bankfull.

above the mid geomorphic feature and sometimes with a break on a depositional bench. At Hickey Run, the high geomorphic feature is the slope break, but is sometimes obscured by scour. At Oxon Run, the high geomorphic feature is located at the back of bench above the mid geomorphic feature and is at the same level as top of point bars (but above the level of lateral bars). The Oxon Run high geomorphic feature also encompasses all areas of gravel deposition.

The exact geomorphic processes forming the three separate indicators are not completely understood and are a subject for further study. The frequency of discharges associated with all three indicators is high. Analysis of gage data from the USGS Watts Branch stream gage shows that the discharge associated with the high indicator is exceeded on average about five times a year (Starr et al., 2003).

The Service observed lateral migration of the Oxon Run channel as a result of the frequent, high flows generated by record precipitation in calendar year 2003. Even though the channel shifted location, the Oxon Run channel reformed the three sets of indicators at approximately the same stages, channel widths and depths. The Service concludes that the low and middle indicators are not remnant features, but are active indicators. We believe that the low feature represents a feature called the "inner berm", which generates a discharge associated with the active stream portion of the bankfull channel. The presence of two indicators above the active channel may indicate seasonal variation in bankfull discharge or an effect of urbanization. Woodyer (1968) noted similar multiple benches in survey of streams in developing areas of New South Wales, Australia.

The multiple field indicators are found consistently in all three streams surveyed and the relative stages and discharges of the indicators are consistent. The Service concluded that all three features indicate important features that should be incorporated in the restoration design. Concept design cross sections are sized to provide the discharge corresponding to the high indicator, but the cross sections also incorporate inner channels sized to fit discharge corresponding to the low and middle indicators.

Design Bankfull Discharge

The Service estimated bankfull discharges for the three indicators at the field locations in Oxon Run, Watts Branch, and Hickey Run using several methods:

- stream gaging in Oxon Run during runoff events;
- gage calibration using recorded stream stages from the USGS Watts Branch stream gage;
- regional relationships between drainage area and bankfull discharge (McCandless and Everett 2002 and McCandless 2003; and
- relationships between channel characteristics and channel roughness (Leopold 1994; Limerinos 1970; and Rosgen 1996).

<u>Stream Gaging</u>

For Oxon Run, the most accurate method of estimating bankfull discharge is active stream gaging during storm runoff events. To date, discharge measurements have been collected only for two runoff events with flow depths that were less than one third of bankfull depth. The flow measurements provide an upper limit to channel roughness (represented by Manning's "n") as channel roughness is expected to be lower at bankfull discharge. Use of other methods is required to estimate bankfull discharge until discharge measurements can be obtained at or near bankfull stage.

Gage Calibration

The Service measured bankfull hydraulic geometry (stage, cross section area, mean depth, and width) in a reach of Watts Branch near the USGS Watts Branch stream gage. Accurate estimates of bankfull discharge at Watts Branch may be made using the stream gage rating curve. Bankfull discharges for the three bankfull geomorphic features (low, mid, and high) are listed in Table 1 along with corresponding values of Manning's "n". Computed values of roughness at the Watts Branch gage are not directly applicable to estimating the bankfull discharges at the Oxon Run concept reaches due to differences in stream characteristics, but they do provide indications of the range of Manning's "n" values found in District streams.

Table 1: Calibrated Discharge – Watts Branch Gage

Geomorphic Indicator	Cross Section Area (ft^2)	Width (feet)	Depth (feet)	Calibrated Discharge (cfs)	Manning's "n"	u/u*
Low	22.8	21.7	1.05	48.7	0.043	6.10
Mid	44.2	24.9	1.78	158	0.036	7.92
High	64.3	28.9	2.23	298	0.032	9.18

Regional Relationships

The Service developed regional relationships between bankfull discharge, bankfull cross section area, mean bankfull depth and bankfull width for the Maryland Piedmont (McCandless and Everett 2002) and Maryland Coastal Plain (McCandless, 2003) physiographic regions. The relationships were developed by field determination of bankfull stage at USGS stream gages.

The District streams are located close to (but below) the Fall Line that separates the Piedmont from the Coastal Plain. The Coastal Plain regional relationships developed by McCandless (2003) were based on gaging stations located in predominantly rural watersheds. Although the District streams are located in the Coastal Plain, the regional relationships developed by McCandless are not necessarily applicable due to the large percentage of watershed imperviousness associated with District Streams,

Figure 4 shows a comparison of the Maryland Piedmont and Maryland Coastal Plain regional relationships for bankfull cross section area, mean bankfull depth, and bankfull width with observations made at eight sites surveyed in Hickey Run, Oxon Run, and Watts Branch.

Inspection of Figure 4 shows that bankfull cross section area and bankfull width for all three sets of bankfull indicators for the District streams are generally larger than the Maryland Coastal Plain relationship. Cross section area is the product of bankfull width and mean bankfull depth. The differences between the District and the Maryland Coastal Plain streams are that District streams are generally wider, which also results in increased cross section area. The larger widths of District streams are likely due to the high degree of urbanization of the District and possibly due to slight differences between the physiography of the District streams and Maryland Coastal Plain streams.

Because the District streams have larger bankfull width than the Maryland Coastal Plain, it is likely that bankfull discharges are greater in the District streams than in the Maryland Coastal Plain. Because the land use and hydraulic geometry of the District's streams are different than the streams used to prepare the Maryland Coastal Plain relationship, the Maryland Coastal Plain relationship for bankfull discharge does not provide a reliable means of estimating bankfull discharge for the Oxon Run sites.

The Maryland Piedmont hydraulic geometric relationships fall close to the District streams, but use of the Maryland Piedmont relationships for the Hickey Run, Oxon Run, and Watts Branch is inappropriate because the relationships are based on streams from a dissimilar hydro-physiographic region.

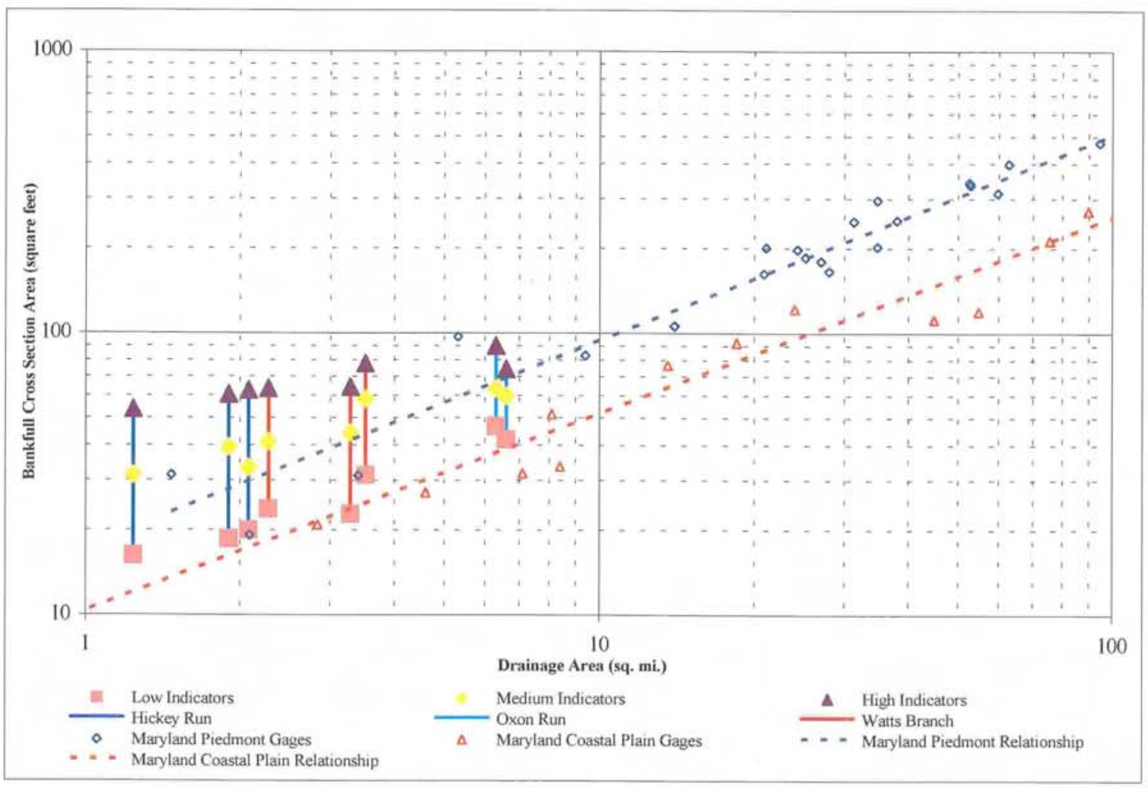


Figure 4(a): Regional Relationships for Bankfull Cross Section Area

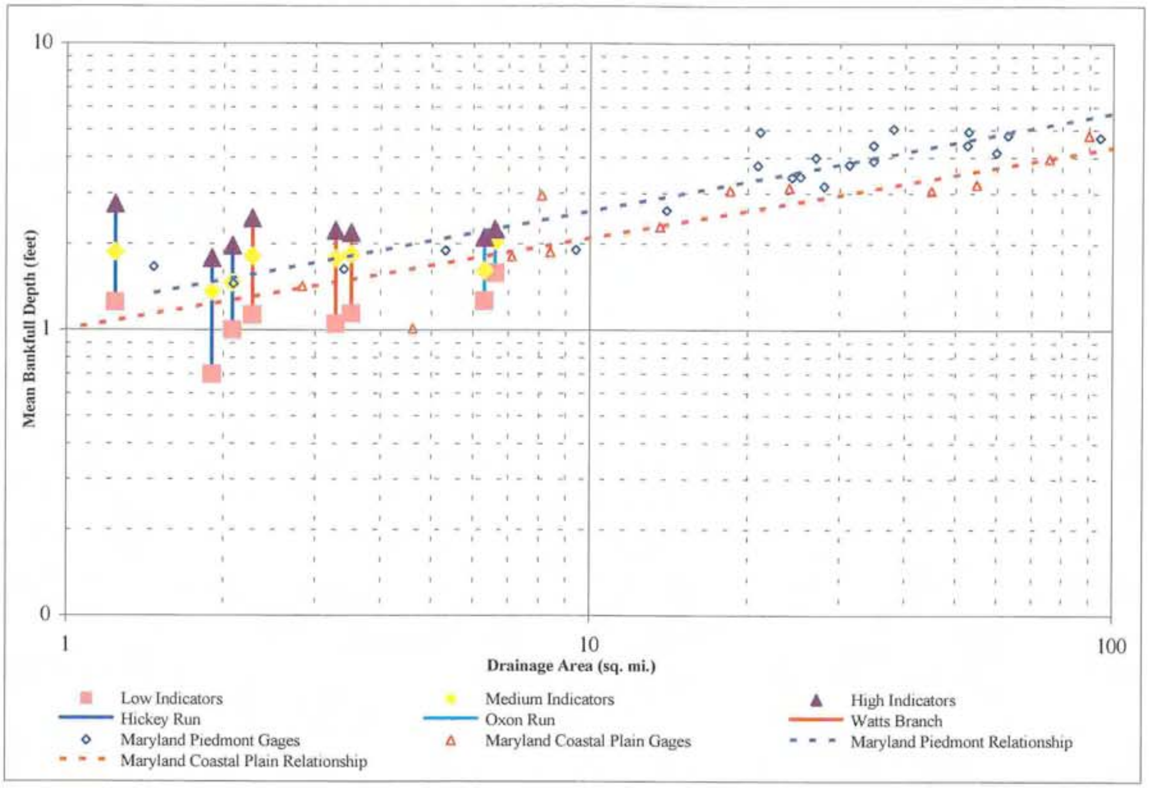


Figure 4(b): Regional Relationships for Mean Bankfull Depth

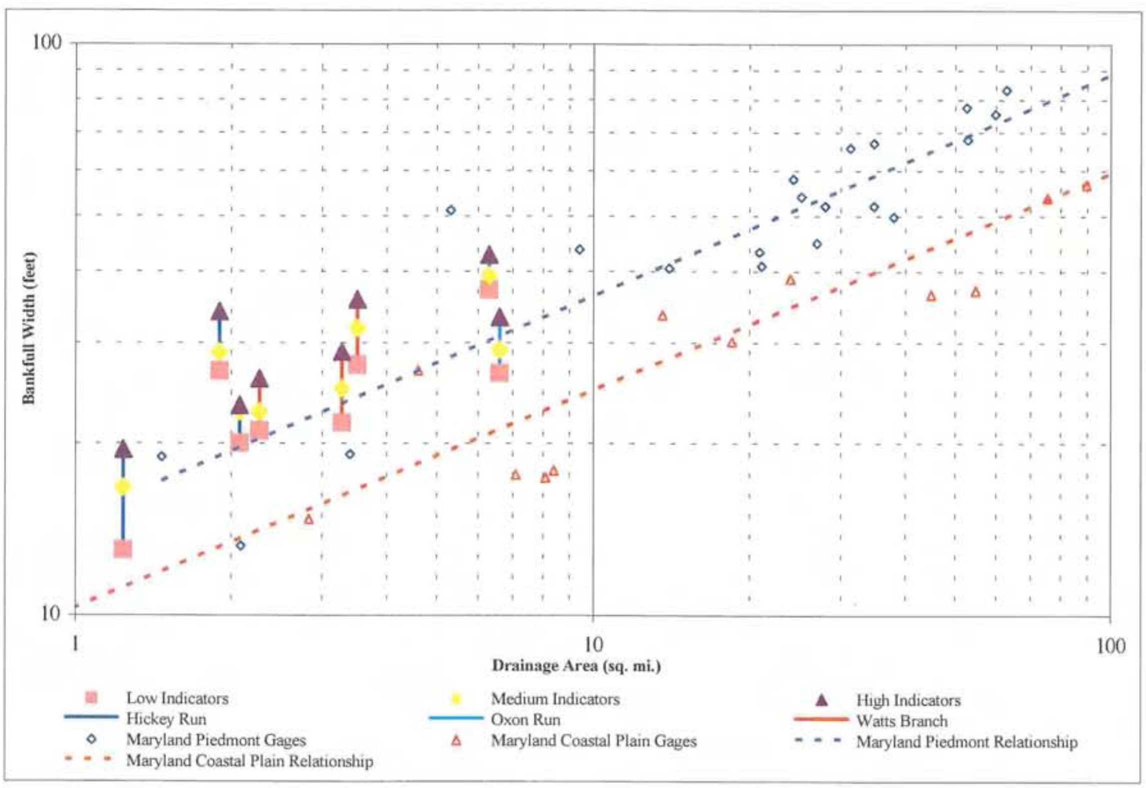


Figure 4(c): Regional Relationships for Bankfull Cross Section Width

Resistance Relationships

Several methods are commonly used to estimate channel roughness and bankfull velocity for ungaged streams. Leopold (1994) and Limerinos (1970) provide a means of estimating bankfull velocity using relationships between friction factor and relative roughness. Relative roughness is the ratio of flow depth to the representative substrate particle size. The Leopold (1994) relationship is based on earlier work by Leopold, Wolman, and Miller (1964) and is similar in form to the Limerinos (1970) relationship:

$$u/u^{*}=2.83 + 5.7 \log R/D_{84} \qquad (1)$$

where:

- R is the hydraulic radius
- u is the depth averaged downstream velocity
- u^{*} is the shear velocity
- D_{84} is the substrate particle size of which 84 percent of the substrate is finer.

Shear velocity is calculated as:

$$u^{*} = (gRS)^{1/2} \qquad (2)$$

where:

- g is gravitational acceleration
- S is the energy slope (assumed to be equivalent to measured slope of bankfull indicators).

Equation (1) is rearranged to solve for velocity. Bankfull discharge is calculated as the product of velocity and bankfull cross section area. Manning's "n" may be estimated by rearranging Manning's equation to solve for "n":

$$n = \phi/u\,(R^{2/3})\,(S^{1/2}) \qquad (3)$$

where:

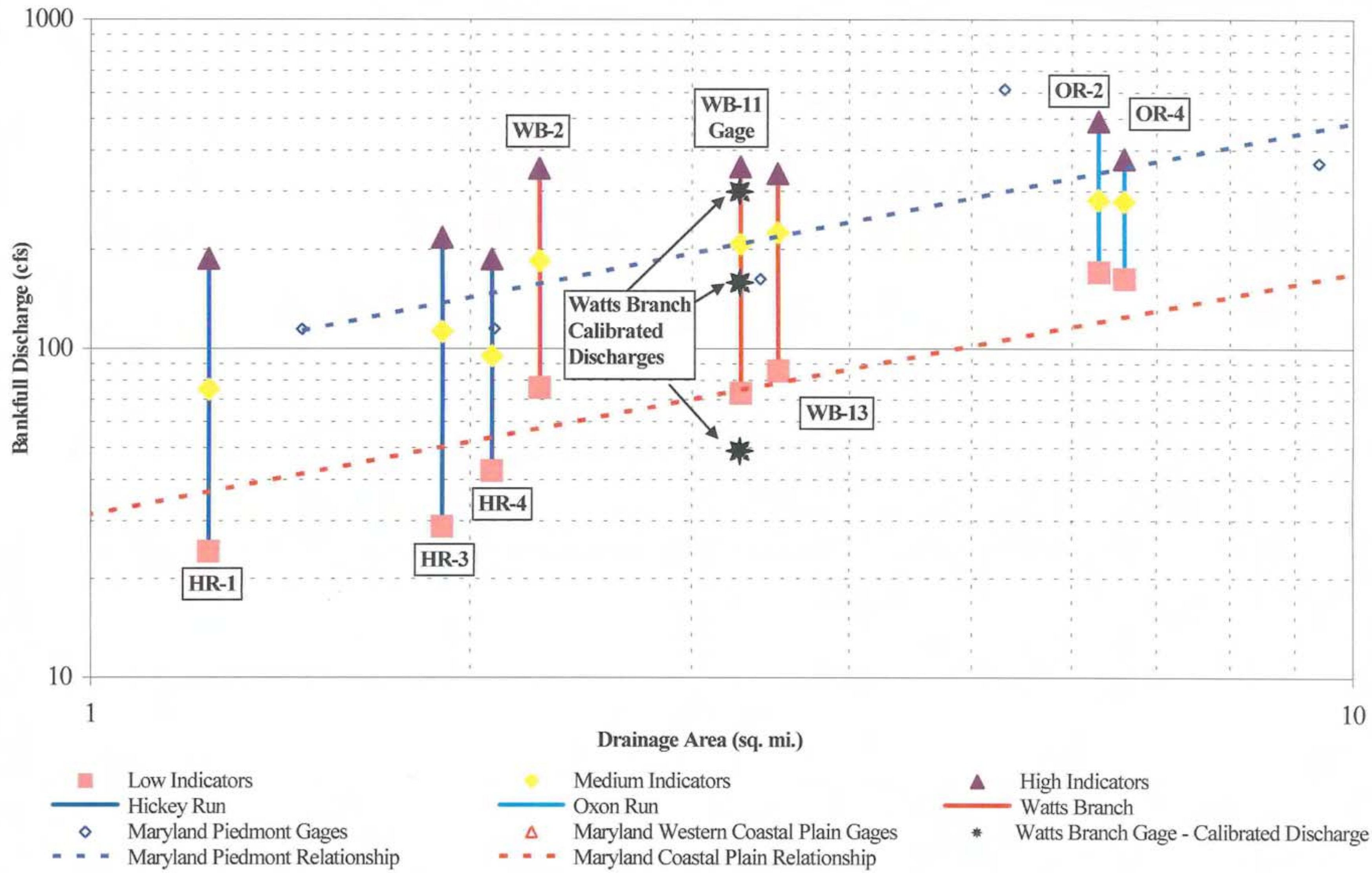
- n is Manning's roughness coefficient; and
- ϕ is a conversion factor equal to 1.486 in English units, and 1.00 in International System of units.

Bankfull discharge was estimated for the District sites for each of the indicators using Leopold 1994. Results are listed in Table 2 and depicted graphically in Figure 5. Figure 5 also shows the Maryland Piedmont and Maryland Western Coastal Plain relationships between drainage are and bankfull discharge; and the calibrated bankfull discharge for the Watts Branch stream gage.

Table 2: Bankfull Discharge Computed using Leopold (1994)							
Stream	**Reach**	**Hydraulic Radius (feet)**	**Bankfull Slope**	**D84 (mm)**	**Bankfull Velocity (ft/sec)**	**Bankfull Discharge (cfs)**	**Manning's "n"**
Low Indicators							
Hickey Run	HR-1	1.16	0.0070	344	1.5	24	0.092
	HR-3	0.65	0.0046	83	1.5	29	0.049
	HR-4	0.85	0.0019	14	2.3	43	0.025
Oxon Run	OR-2	1.22	0.0050	42	3.7	171	0.033
	OR-4	1.44	0.0040	36	3.9	163	0.031
Watts Branch	WB-02	1.04	0.0034	21	3.2	76	0.028
	WB-11	0.97	0.0039	23	3.2	73	0.028
	WB-13	1.12	0.0022	21	2.7	86	0.027
Mid Indicators							
Hickey Run	HR-1	1.71	0.0070	344	2.4	75	0.074
	HR-3	1.26	0.0046	83	2.9	112	0.041
	HR-4	1.29	0.0019	14	3.1	95	0.024
Oxon Run	OR-2	1.57	0.0050	42	4.5	283	0.032
	OR-4	1.85	0.0040	36	4.7	280	0.030
Watts Branch	WB-02	1.64	0.0034	21	4.5	185	0.027
	WB-11	1.62	0.0039	23	4.7	208	0.027
	WB-13	1.78	0.0022	21	3.9	225	0.027
High Indicators							
Hickey Run	HR-1	2.43	0.0070	344	3.5	188	0.064
	HR-3	1.64	0.0046	83	3.6	218	0.039
	HR-4	1.82	0.0019	14	4.0	187	0.024

Table 2: Bankfull Discharge Computed using Leopold (1994)							
Stream	**Reach**	**Hydraulic Radius (feet)**	**Bankfull Slope**	**D84 (mm)**	**Bankfull Velocity (ft/sec)**	**Bankfull Discharge (cfs)**	**Manning's "n"**
Oxon Run	OR-2	2.04	0.0050	42	5.5	491	0.031
	OR-4	2.04	0.0040	36	5.1	376	0.030
Watts Branch	WB-02	2.19	0.0034	21	5.6	353	0.026
	WB-11	2.03	0.0039	23	5.5	357	0.027
	WB-13	2.11	0.0022	21	4.4	340	0.026

Figure 5: Bankfull Discharge Estimated using Leopold 1994



Comparison of the range of values of Manning's "n" calibrated for the Watts Branch gage (0.043 – 0.032) with the values produced by Leopold's (1994) relationship (0.028 – 0.027) indicate that at least for the Watts Branch gage that the Leopold (1994) under-predicts roughness and over-predicts discharge and velocity.

While the Watts Branch stream gage is only one data point, comparison of the predicted bankfull discharges for Oxon Run Reach OR-2 and OR-4 also suggests that the Leopold (1994) relationship may not provide accurate estimates of channel roughness for District streams. Reaches OR-2 and OR-4 are located in close proximity to each other and there are only minor inflows from storm sewer outfalls to Oxon Run between the two reaches. Bankfull discharge estimates should be similar at both cross sections, but the estimate for the high bankfull indicators in Reach OR-2 is over 100 cfs greater than for Reach OR-4 downstream. The physical characteristics of the two reaches are different (See Table 3). Reach OR-2 is wider, has a larger cross section area, and a steeper slope (0.0050 vs. 0.0040). Reach OR-2 has significant form resistance created by meanders and large amounts of vegetation within the bankfull channel. Reach OR-4 was straightened, has low form drag, and has little vegetation within the bankfull channel. The Leopold (1994) relationship fails to account for the differences in form drag created by vegetation and meanders at higher discharges.

Table 3: Hydraulic Geometry: Oxon Run Reach OR-2 and OR-4

Geomorphic Indicator	**Cross Section Area(ft^2)**		**Width (feet)**		**Mean Depth (feet)**	
	OR-2	**OR-4**	**OR-2**	**OR-4**	**OR-2**	**OR-4**
Low	46.6	41.8	37.1	26.5	1.26	1.58
Mid	63.4	59.5	39.3	29.1	1.61	2.04
High	89.9	74.3	42.7	33.2	2.10	2.24

Discussion

Accurate estimates of bankfull discharge for Oxon Run under existing conditions require additional stream gaging at or near bankfull flows. Use of regional relationships for the Maryland Coastal Plain established by McCandless (2003) is not appropriate because of apparent differences in District streams and the data set used to develop the Maryland Coastal Plain relationship. Use of resistance relationships appears to not reflect the influence of form drag and vegetation on discharge. At this time, an approximate range of bankfull discharge may be estimated for design purposes by assuming a range of likely values of Manning's "n" for the constructed stream. Based on review of the discharge analysis, it appears that a Manning's "n" in the range of 0.032 to 0.035 is appropriate for existing reaches of Oxon Run. This implies a range of 434 to 475 cfs for existing bankfull discharge for the high indicator. A value of 455 cfs is used for the design bankfull discharge for both concept reaches. This value may be altered if more gaging information is obtained.

Figure 6: Typical Maryland C4 Stream – Basin Run at Liberty Grove, MD

The roughness of constructed streams is lower than for natural streams as constructed streams lack established vegetation and imbricated sediment features. A Manning's "n" value of 0.032 will be used for analysis of the constructed stream at bankfull discharge.

4. Design Stream Type

Stream classification is used also as a basis for selecting appropriate stream characteristics for the restored streams. By selecting an appropriate stream type, the Service defines the range and combinations of geomorphic variables of the restored stream. Stream processes are inferred from stream type. The selected stream type must be an appropriate type for the geomorphic characteristics of the stream valley. A suitable stream type is selected that is appropriate for the landscape (*i.e.*, valley type, valley slope, floodplain, etc.) and the anticipated discharge and sediment loading regime.

During the assessment phase, the Service determined that a C4 stream type would be appropriate for the Oxon Run main stem given its location within the Western Coastal Plain, stream order, the characteristics of the valley, valley slope, sediment load, and discharge. A C stream type is a meandering, alluvial stream, well connected with its floodplain. It is found (among other locations) in the broad valley type in which Oxon Run is located. The "4" indicates that the median size of stream materials is gravel; typical of the materials currently in place in the natural stream reaches of Oxon Run. Figure 6 shows a typical Maryland C4 stream with features similar to the proposed stream type for Oxon Run. Bed features of C stream types include a well-developed pool-riffle sequence and the stream's morphology generally provides good habitat potential for fish and macroinvertebrates. The selection of a C4 stream type indicates that the restored stream reaches will be slightly entrenched, possess moderate to high width depth ratios, and have moderate to high sinuosities. A C4 stream type will restore habitat, and reduce stream width and stream incision. Lower stream incision will decrease erosive stresses during major flow events.

5. Reference Reaches

Natural channel design methodology employs the characteristics of stable streams as a template for designing restored streams. Selection of a stream type identifies the broad characteristics for the restored stream, but does not provide sufficient design parameters to develop stream restoration plans. Additional geomorphic measurements must be collected from stable streams that fully detail the characteristics of the stream cross section, planform, and profile. A stream possessing stable characteristics that may be used as a template for design is termed a "Reference Reach." The primary requirement of a reference reach is that the stream reach is stable. Reference reaches are not required to be in a natural, undisturbed state.

A suitable reference reach and the restored reach must possess similar hydrologic, geologic, and physiographic characteristics. The shape of a particular stream represents the balance between erosive forces applied to a stream by water flowing down a slope and the resistive forces supplied by native stream substrate and streambanks. Streams formed in differing types of alluvium or rock respond differently to the same hydrology. Likewise, streams of the same lithology and geology exhibit differing forms if subjected to differing hydrologies. For example, compare two streams within the same area, one of which possesses an undeveloped watershed and the other possessing an urbanized watershed. Because urbanization changes the timing and volume of storm flows, the urbanized stream will enlarge. Because of differences in the response of streams to differences in boundary conditions (*i.e.*, stream flow, vegetation, geology, and lithology), it is important to select a reference reach with similar hydrophysiographic characteristics. Generally, this would be a stream located in the same general area, but streams from remote locations may be used for reference reaches if there is close similarity in boundary conditions (Hey, in press).

During the Oxon Run Assessment, the Service was unable to identify a suitable reference reach for the urban streams in the District. Finding a suitable reference reach is unlikely as most streams in the region have been relocated or straightened. The imposition of urban infrastructure such as bridges, culverts, and sewer systems has created structural controls that obscure natural stream characteristics or otherwise preclude their use as reference reaches.

The hydrologic responses of drainage basins in and around the District have been altered by development. Stream flow typically consists of a regime of flashy stormflow and very low base flow. Suitable reference reaches must have similar hydrology. As urbanization impacts are still developing, no suitable reaches have been identified that have adjusted to stable conditions, possess good habitat features, and whose shape is not controlled or influenced by urban infrastructure.

Given the lack of identified reference reaches and the low potential for suitable reference reaches to be identified in the future, other methods must be employed to identify geomorphic design parameters for restoration of urban streams in the District.

6. Use of Regional Stream Morphologic Data

The Service developed design parameters for the Oxon Run concept plans using a set of characteristic geomorphic data from C4 streams with similar physiographic settings in the Western Maryland Coastal Plain and Maryland Piedmont physiographic provinces. Characteristic data was obtained from a comprehensive survey of streams in Maryland that the Service collected to develop regional relationships between bankfull discharge, bankfull width, bankfull mean depth, and drainage area. Two of these studies focused on streams in the Maryland Piedmont (McCandless and Everett 2002) and Maryland Coastal Plain (McCandless 2003) physiographic provinces. The studies collected detailed geomorphic measurements and prepared detailed geomorphic mapping for streams in the vicinity of USGS gage stations. The advantage of collecting the data near gaging stations is that measured discharge ratings from the gages are used to estimate discharge and velocity for bankfull indictors at nearby study locations.

The Maryland stream survey data contains many of the relationships that are required to develop natural stream designs. There are several caveats that must be considered when employing the Maryland Stream Survey data to develop stream restoration designs for the District:

- Many of the study sites are altered from natural conditions and possess local structural controls such as bedrock and infrastructure.
- The selected streams are from rural areas with much lower rates of watershed imperviousness.
- They may not possess the same hydrologic, geologic, and physiographic characteristics as streams in the District.
- Streams in the Maryland Stream Survey are not necessarily representative of reference reach conditions. Streams were not evaluated for habitat quality.

The Service developed a subset of selected streams to provide a set of characteristic data describing Rosgen C4 stream types (Table 4). The study reaches for the Piedmont and Western Coastal Plain[4] were examined. Only C4 streams were selected. This dataset was further reduced to select streams with stream slopes ranging from 0.001 to 0.010. Very low-gradient Coastal Plain streams and steeper Piedmont streams were eliminated.

[4] The District lies along the border between the Piedmont and Western (Chesapeake Bay) Coastal Plain. Review of streams in the Western Coastal Plain portion of the District found that the discharge relationships fell between the two physiographic provinces rather than matching the Western Coastal Plain. This may be the result of urbanization or it may reflect that the District is in a transition zone. Regardless, both Western Coastal Plain and Piedmont Streams were used to develop a characteristic data set of C4 streams.

Table 4: Characteristic C4 Streams from Maryland Stream Survey						
Study Reach	**Drainage Area (mi^2)**	**Bankfull Discharge (cfs)**	**Mean Bankfull Depth (feet)**	**Physio-graphic Province**	**Sinuosity**	**Average Stream Slope**
Basin Run at Liberty Grove, MD	5.31	614	1.89	Piedmont	1.4	0.0059
Patuxent River near Unity, MD	34.8	1050	3.89	Piedmont	1.26	0.0021
Piney Creek at Taneytown, MD	31.3	1390	3.78	Piedmont	1.47	0.0025
Mattawoman Creek near Pomonkey, MD	54.8	540	3.06	Western Coastal Plain	1.4	0.0013
St. Mary's River at Great Mills, MD	24.0	465	4.78	Western Coastal Plain	1.4	0.0014

The Maryland Stream Survey data are not reference reach data. Given the lack of reference reaches for District and Maryland streams, however, the selected C4 streams from the Maryland Stream Survey provide information on the range and mean values of geomorphic parameters found in the region that may be used to validate geomorphic parameters used in the preparation of Oxon Run stream restoration plans.

7. Selection of Morphological Characteristics for Restoration of Oxon Run

The Service selected target ranges of morphological characteristics for the restoration reaches on the basis of selected stream type for the restoration and the restoration objectives. The Service reviewed data from the Maryland stream survey to determine the population ranges of geomorphic variables that are present in Maryland streams. Specific values and ranges of geomorphic parameters for Oxon Run were compared to the Maryland stream survey data. Generally, the Service selected design geomorphic parameters for the restoration that stayed within the range of the Maryland characteristic data except when engineering judgment suggested that other values might be more effective in achieving restoration goals. For example, The Service selected higher ratios of radius of curvature to bankfull width for the concept plans because constructed streams possess less resistance to meander migration forces than mature stream systems. Higher ratios of radius of curvature to bankfull width reduce the potential for bank erosion until deep-rooted vegetation can become established and protect the constructed stream.

Appendix B lists final values used in the design, field-measured values of existing conditions in Reaches OR-2 and OR-10, the range and mean values for Maryland characteristic data, and data developed by Rósgen (unpublished) for Colorado C4 streams.

8. Cross Section Geometry

The Service developed multi-stage riffle, pool, glide, and run cross sections for Oxon Run Reach 2 and 9B. The geomorphic analysis identified target values of bankfull cross section area, mean bankfull depth, the ratio of bankfull width to bankfull depth, and the ratio of maximum bankfull depth to mean bankfull depth for each of the three geomorphic features (low, mid, and high). The Service developed each cross section to provide the target cross section area and bankfull width at the bankfull depth for low, middle, and high indicators.

The cross sections were shaped using a dimensionless hydraulic geometry procedure adapted from Rosgen (1999). The procedure provides information about how channel width and cross section area change with depth in typical Maryland C4 streams. The Service extracted cross section data from the set of Maryland characteristic streams. Dimensionless ratios of width/bankfull width, depth/bankfull depth, and cross section area/bankfull cross area were computed for stages ranging from zero up to bankfull stage. The Service plotted dimensionless cross section area and dimensionless width versus dimensionless depth (Appendix C). The Service compared dimensionless curves for the proposed riffle cross sections with the Maryland characteristic data. Dimensionless curves for the proposed riffle cross section (for low, middle, and high geomorphic indicators) plot within the range of the Maryland data.

C. Development of Restoration Design

The following sections detail preparation of concept plans. The Service stated plan development by developing topographic mapping of the two representative reaches, The next steps are developing of stream planform in accordance with the selected geomorphic parameters, layout of in-stream structures which are dependent on the relative location of pools and riffles, and then development of the stream vertical profile. The Service then uses the Terramodel® CADD package to prepare grading and earthwork computations. Final design work involved developing stormwater retrofit concepts compatible with stream restoration designs.

1. Mapping

The Service developed topographic mapping for each of the restoration reaches using a total station. The Service prepared topographic maps in Terramodel. The surveys collected detailed topographic information for the existing stream reaches and adjacent floodplains. The Service attempted to tie the topographic maps to horizontal and vertical control networks. Discussions with the District Surveyor revealed that the District does not maintain a horizontal control network that could be used to tie-in mapping. The Office of the Surveyor does maintain a listing of secondary vertical bench marks, but many of these proved to be unreliable due to their age and lack of association with permanent features. Approximate horizontal control was achieved by overlaying surveys with aerial photos of the project areas. Approximate vertical control was established for Reach OR-9B using bench marks at the Wheeler Avenue Bridge. Approximate vertical control at Reach OR-2 was established using invert elevations for WASA storm sewers.

Preparation of final design and construction will require tying in surveys to established bench marks. Discussions with WASA indicate that they may possess bench mark data that can be used for future work.

2. Planform Layout

The Service evaluated a number of trial planforms (stream alignments). Trial alignments were developed in Terramodel and alignment data extracted to a text file. The Service entered alignment data into a spreadsheet program to determine if the distribution of curve (meander) and riffle lengths produce acceptable ratios of meander lengths to bankfull width and pool-to-pool spacing. Preliminary checks were made to evaluate vertical or horizontal conflicts with sanitary sewers.

Note that the alignment follows the centerline of the stream not the stream thalweg. The deepest part of the cross section is skewed off the centerline in pools.

3. Structure Layout

Cross-vanes and J-hooks (Rosgen 2001) are used to reduce shear stress along the outer banks of meander curves:

- Cross-vanes which consist of a sill used to set grade elevation that is placed in the central third of the bankfull stream; and two vanes that extend from each end of the sill in the downstream direction at an angle of 25-30 degrees from the centerline of the stream and tie into the streambanks at the bankfull elevation. Cross-vanes concentrate the flow into the center of the stream and create a local contraction in the width of flow.
- J-hook vanes (J-hook) which are comprised of a single vane located in the outer third of the stream on the outside of meander bends and contain a cross-over sill in the form of a hook.

The vanes of cross-vanes and J-hooks provide bank protection by redirecting flow away from banks. The zone of protection created by the vanes extends for approximately one vane length downstream of the end of the vane and about one half vane lengths upstream of the sill.

Riffle Crest Controls are placed at the upstream end of riffles. A Riffle Crest Control consists of a line of large rock placed at and below the finished grade at the start of riffles and that extends to bankfull channel elevation. In nature, riffles are developed by stream sorting processes over long periods of time. Rock is moved and transported into place. Typical formations at the head of riffles consist of tightly packed, coarse-sized particles in a stable structure (Sear 1996). The particles forming the head of the riffle represent the largest-sized particles found in the streambed. During construction, the natural imbrication of particles created by stream sediment transport processes is lost. Sediment graded into form riffles does not have the same resistance to movement found in naturally formed riffles. The Riffle Crest Control provides a hard-point in the stream to stabilize the head of riffles immediately after construction. Flow over a Riffle Crest Control will initiate the resorting of particles that takes place in natural riffles. Over time, stream sediment transport processes will resort particles and form a resistant riffle.

Cross-vanes, J-hooks, and Riffle Crest Controls are designed to have a long service-life, but their most important function is to protect streambanks and riffles during the first several years after construction before vegetation becomes fully established and the streambed has stabilized.

The Service developed trial structure layouts using an Excel spreadsheet. Placement of structures followed rules developed by Rosgen (2001). The structure layouts were evaluated for number and frequency of structures. As individual structures are expensive, it was preferable to make adjustments in the planform that minimized the total number of structures.

4. Development of Vertical Alignment

Average bankfull slope was determined by dividing the elevation drop by the length of the stream centerline. Stream thalweg was developed in several steps using a spreadsheet. The Service set head and tails of riffle sections to achieve a riffle slope 1.8 times the bankfull slope and an average riffle depth equivalent to the target riffle depth. Pool elevations were set to provide a range of elevations around the target maximum pool depth. The Service increased or decreased depths if reaches were longer or shorter than average. Glides and runs were set to tie into pools and riffles and to meet target depths.

5. Earthwork and Disturbance Analysis

The Service set up grading templates in Terramodel that produced the design cross sections. Terramodel functions were employed to construct the grading plan for the stream restoration, to produce a projected condition DTM, and to estimate amounts of cut and fill.

A general goal of the earthwork analysis was to achieve a balanced job (*i.e.*, the amount of cut equals the amount of fill). If the earthwork analysis indicated that the job did not balance, the Service made adjustments in the alignment or to the vertical profile.

6. Stormwater Retrofit

The Service developed rough conceptual solutions for stormwater management retrofits. Only limited engineering analysis was performed as solutions for stormwater management are sensitive to minor adjustments in the stream restoration plan. Conceptual solutions show the location and type of retrofit, but computations have not been performed to validate hydraulic profiles, pond volumes, or to determine pollutant removal efficiencies.

D. FLOODPLAIN ANALYSIS

1. FEMA Regulations

The Federal Emergency Management Agency (FEMA), which oversees the National Flood Insurance Program (NFIP), prepared a Flood Insurance Study for the District in 1985 that established the 100-year floodplains and a floodway for Oxon Run (FEMA 1985). FEMA defines the 100-year floodplain as the area inundated by a discharge with a return period of 100 years. A floodway is a protected zone with a defined boundary within the floodplain that provides the majority of flood conveyance. The floodplain fringe is the area within the 100-year floodplain, but outside the floodway. Restricted development is allowed within the 100-year floodplain, but prohibited from the floodway. Appendix D shows copies of the FEMA floodplain maps for Reaches OR-2 and OR-9B.

FEMA regulations were developed to reduce flood risk by preventing any development within the floodway and only limited development within the floodplain fringe. Because stream restoration of Oxon Run will result in changes to the FEMA floodway and floodplain, the stream restoration is subject to permitting under FEMA regulations. DOH and the Service must demonstrate through hydraulic analyses that the proposed stream restoration does not impact flood elevations.

FEMA delegated authority for enforcing floodplain management regulations to the District government. Applications for floodplain modifications are reviewed and approved by the District Department of Consumer and Regulatory Affairs (DCRA).

2. Hydraulic Analyses

Several hydraulic analyses are required to evaluate compliance with FEMA floodplain regulations. Applicants for changes in the floodplain must obtain, if possible, copies of the hydraulic models used to prepare the original floodplain mapping. The applicants must replicate, if possible, the *original existing conditions model*. If conditions have changed, or more detailed information is available to conduct the study, applicants may create a *modified existing conditions model*, which represents a more accurate analysis of existing hydraulic conditions. The applicant develops a *proposed conditions model*, which represents conditions after development.

The original hydraulic model used to prepare the Oxon Run floodplain was coarse. Because more detailed information is available from topographic surveys, a *modified existing conditions model* will more accurately reflect current conditions in Oxon Run. Accordingly, to evaluate floodplain impacts of the concept stream restoration plans, the Service developed a *modified existing conditions model* and a *proposed conditions model* for each site using HEC-RAS.

The Service used the FEMA discharges to prepare the floodplain analyses. FEMA discharges were developed using U.S. Soil Conservation Service (SCS) hydrologic methodology (SCS 1975). The Service estimated discharges using USGS Urban Flood Frequency methods (Sauer et al. 1983). Flood frequency relations developed by FEMA and by USGS methods are similar. The Service used the FEMA flood frequency relationships to develop the hydraulic analyses for 10-, 50-, 100-, and 500-year events.

Floodplain impacts are evaluated by comparing the extent of and water surface elevations of the 100-year floodplain. Minor increases (less than 0.1 foot) in water surface elevations are generally considered as having no impact. Increases in water surface elevation greater than 1.0 foot are not permissible. Further, any increases in the extent or elevation of water surface elevations on property owned by others requires agreement by the other property owners before approval by FEMA. Thus, restoration alternatives that create increases in the extent or elevation of flooding beyond the limits of land controlled by the District or onto private land are undesirable. If HEC-RAS models indicated unacceptable increases in flood elevations or extents, or increases in flood risk to adjacent properties, then the proposed restoration alternative was modified to reduce increases.

E. Design Validation

The Service tested the concept designs by conducting a series of hydraulics and sediment transport analyses to ensure that designs will function as intended. Hydraulic analyses of the proposed designs are prepared using the HEC-RAS data set for proposed conditions. Discharges for the hydraulic analyses range from 50 percent of the bankfull discharges up to four times the bankfull discharges.

HEC-RAS is a one-dimensional hydraulic model that reports conditions on a cross-section averaged basis. HEC-RAS may not represent well the processes that are important to natural channel design. For example, flow entering pools and flowing through meanders has important cross–stream velocity components. Assumptions based on cross-section averaged conditions do not apply where the flow is non-homogeneous. Use of HEC-RAS, however, allows evaluation of general flow conditions and may highlight problem areas. For example, if floodprone areas are properly designed, then the total shear stress reported by HEC-RAS should reach a maximum near bankfull discharge and then start to decrease.

HEC-RAS results were reviewed to evaluate how well flow depths and velocities compared with proposed values developed in the concept designs. Shear stresses were evaluated at bankfull, half bankfull, and flood prone discharges to ensure that the shear stresses are within acceptable ranges for bank stability. Flows were evaluated at low flows (small fractions of bankfull discharge) to evaluate habitat potential at low flows. Shear was evaluated to ensure that there is sufficient shear to move target particle sizes without creating excessive shear that might degrade the bed of the restored stream. The Shield's equation was used to test particle mobility.

F. Cost Estimates

1. Development of Cost Estimates

The Service developed concept level cost estimates for the two representative reaches. The Service estimated unit costs for standard construction items using bid tabulations for stream restoration projects recently bid for projects in Washington, DC and the metropolitan areas of Maryland. Projects included development of fish passage structures in Rock Creek Park by the Maryland State Highway Administration, and stream restoration projects constructed by Montgomery, Anne Arundel, and Baltimore Counties. Major elements of the cost estimates are summarized in Table 5. Detailed cost estimates prepared for construction and bidding will contain more line items for materials such as silt fence, erosion and sediment controls, and planting. These costs have been lumped into single items for preparation of the concept level cost estimates.

Table 5: Cost Estimate Development		
Item	**Units**	**Comments**
Class 5 Excavation	Cubic yard	Earthwork computed from grading plans
Cross-vanes	Linear foot	Computed from total length of structures
J-hooks	Linear foot	Computed from total length of structures
Riffle Crest Control	Linear foot	Computed from total length of structures
Channel substrate(Reach OR-9B only)	Cubic yard	Active channel area times depth of six inches
Seeding	Square yard	Disturbances area computed from grading plan
Planting plan (trees & shrubs)	Square yard	Planting based on area of disturbance above bankfull. Average cost assumes mixture of native trees and shrubs. No additional planting included for augmentation of existing park lands.
Bioengineering bank stabilization	Linear foot	Bioengineering installed on outside of meander curves
Stormwater retrofits	Lump sum	Concept level cost estimates developed based on rough concept plans.
Removal and disposal of concrete channel	Square yard	Unit prices available from two projects (Rock Creek Park and Olen Drive Fish Passage – Anne Arundel County) that involved removal and disposal of concrete channels.
Maintenance of stream flow	Lump sum	5-6 percent of base construction costs[5]
Erosion and sediment control	Lump sum	7 percent of base construction costs
Clearing and grubbing	Lump sum	1 percent of base construction costs – Reach OR-B 4 percent of base construction costs – Reach OR-2
Construction stakeout	Lump sum	2-4 percent of base construction costs
Mobilization	Lump sum	5 percent of base construction costs

[5] Base construction costs include materials, excavation, and construction costs.

Table 5: Cost Estimate Development		
Item	**Units**	**Comments**
Contingency	Lump sum	15 percent of base construction costs
Engineering	Lump sum	8-12 percent of total construction costs[6]
Permitting and contracting	Lump sum	0.5 percent of total construction costs

2. Potential Cost Savings

Cost estimates are based on typical costs for constructing stream restoration projects in the Maryland and District metropolitan areas. The Service believes that there are ways of reducing the typical "costs of doing business" through alternate contracting methods, construction supervision, construction inspection, and partnership agreements.

There are also potential cost savings that may result from the scale of the project. Analysis of projects constructed by Baltimore County and Montgomery County shows mobilization costs and other project unit costs drop as the size of the project increases. Costs for equipment are lower if longer lease periods are used.

WASA anticipates constructing improvements to the Oxon Run Collectors between 13th Street and Southern Boulevard in 2005. Sequencing construction activities to occur simultaneously might reduce costs.

Some additional cost savings may be generated by:

- Using large trees salvaged during construction to construct cross-vanes and vane arms of J-hooks.
- Reusing some of the material from the concrete channel as buried footers for cross-vanes, J-hooks, or Riffle Crest Controls.

[6] Total construction costs include base construction costs and support activities (maintenance of stream flow, erosion and sediment control, clearing and grubbing, and construction stakeout).

III. CONCEPT PLANS - OXON RUN REACH 2

A. Description

1. Location/Physiography

Oxon Reach 2 (OR-2) is located on the main stem of Oxon Run, 460 feet downstream of where Oxon Run enters the District (Figure E-1 in Appendix E). Reach OR-2 is a B4c type stream with an average riffle bankfull width of 51.3 feet; riffle bankfull mean depth of 1.8 feet and riffle cross-sectional area of 92.1 feet^2. Bankfull dimensions in the other meandering reaches of Oxon Run are similar. Bottom material consists of coarse gravel. Sediment supply is high (ranging from 0.8-0.15 tons/foot/year), and the bed is mobile. Extensive gravel bars and transverse bars are common. There is moderate development of riffles and pools. Large woody debris is common in these reaches, due to trees falling from eroded banks. Deep scour holes exist where trees have fallen into the stream. The trees also trap floating litter and bottles. The low bank is about 4-5 feet high, with the high banks significantly taller, around 8-9 feet. The stream is bounded by an entrenched stream channel within the floodplain. Flow out of the stream onto the floodplain is rare.

The water is generally clear, except after a rainfall, but often has a sewage odor. In some areas, there are noticeable oil slicks on the water, and/or reddish staining on the rocks. Trash is present and ranges from small debris such as wrappers and aluminum cans to shopping carts, and in several instances, cars and motor-scooters. Aquatic habitat quality is poor to fair, and fish are rarely seen. Aquatic habitat rating is based on impaired water quality, lack of good quality pools, lack of sufficient water depth in riffles to allow passage of fish, the mobility of the bed, which disrupts spawning activity, and significant changes in bed elevation, which constitute a barrier to fish passage.

The reach flows through land maintained by the NPS. The park land is bounded by Southern Avenue, Mississippi Avenue, and 13th Street. The area is maintained as natural park land and is forested with mature stands of trees. There is development along the periphery of the park. There is a residential community on the south side of Reach OR-2 located in a triangular wedge that fronts Southern Avenue. A new building has been constructed at the corner of Mississippi Avenue and Southern Avenue. A basketball court and playground is located on the north side of Reach OR-2 adjacent to Mississippi Avenue and opposite Stanton Avenue. The NPS indicates that they expect no further development within the park land and no changes in land use.

2. Utilities

Storm Sewer Outfalls

Four storm drains empty directly into the stream within the project reach. Figure E-2 shows existing utilities and other existing site conditions. These storm drains have caused visible erosion in the streambank and bed adjacent to the outfall, and often on the opposite bank as well. The outfalls are elevated 1-2 feet above the existing streambed. One of the storm drains, a 60-inch storm sewer that originates from Stanton Road, possesses a large outfall structure with wing walls that project into the stream at a bend in the stream. Bank erosion has eroded a deep (5.5 feet) pool immediately upstream of the outfall structure. Turbulence and back eddies during storm flow events are creating rapid rates of bank erosion upstream of the structure.

Sanitary Sewers

Two sanitary sewers run parallel to Oxon Run (Oxon Run collectors). On the south side of Oxon Run is a 24-inch line constructed in 1941. A newer 42-inch sanitary sewer runs along the north side of Oxon Run. The 24-inch sanitary sewer is in poor condition. Stream erosion has exposed the 24-inch sanitary sewer in several locations in the stretch between Southern Avenue and 13th Street. Exposure resulted in failure of the 24-inch sanitary sewer in several locations. WASA reports that bulkheads have been placed upstream and downstream of the failed sections of the 24-inch sanitary sewer. Cross-connections between the 24-inch and 42-inch sanitary sewer route sewage around the blocked-off sections.

WASA believes that the 24-inch sanitary sewer is required to provide excess flow capacity for the 42-inch sanitary sewer during periods of high flow. Additionally, sewage from the Valley Terrace community, located on the south side of Reach OR-2, flows into the 24-inch sanitary sewer, and then through a cross connection into the 42-inch sanitary sewer. WASA is conducting a feasibility study of improvements for the Oxon Run Collectors in the area between Southern Avenue and 13th Street. Potentially, the 24-inch sanitary sewer may be rehabilitated, abandoned, or reconstructed and relocated.

In the vicinity of Reach OR-2, the 42-inch sanitary sewer is located well away from the stream and does not present conflicts with stream restoration concepts. The 24-inch sanitary sewer lies in and adjacent to the existing stream. Because of the poor condition of the 24-inch sanitary sewer, the Service assumed that it would be relocated away from the stream and that there would be no conflicts with the restored stream.

Note that the locations of the 24-inch and 42-inch sanitary sewers downstream of Reach OR-2 present conflicts for restoration of the reaches below OR-2 and above 13th Street. Below Stanton Avenue, the 24-inch and 42-inch sanitary sewers approach each other at an oblique angle that pinches the stream corridor to less than 100 feet opposite 15th Street.

3. Camp Sims

From 1904 to 1958, the DC National Guard operated a firing range facility, Camp Simms, adjacent to Oxon Run (EA Engineering 1998). As part of the Camp Simms site investigation and remedial activities, a number of unexploded ordnance were identified and removed from the premises. There is a large concrete structure located on the south side of Oxon Run near the bottom of Reach OR-2. The Service believes that the structure may have been associated with Camp Simms.

B. Design Assumptions

The primary goals for stream restoration design are to develop a stream capable of maintaining a stable, self-maintaining state and to improve stream habitat. There are a number of stream planforms that could accomplish these objectives, but there are additional objectives that must be factored into developing the design at Reach OR-2:

- **Minimize disturbance**: Discussions with NPS indicated that the mature forests surrounding Reach OR-2 provide valuable interior forested dwelling space and habitat for neo-tropical bird species. NPS generally supports the goals of the stream restoration, especially habitat improvement, but urged that restoration designs minimize disturbances to mature trees.
- **Minimize earthwork:** Initial cost estimates showed that excavation costs could be a large factor in total construction costs. Therefore, plan development worked to minimize the total amount of excavation.
- **Floodplain management goals:** The 100-year floodplain is located within the boundaries of the NPS park land. Alteration of the stream for stream restoration should not create any impacts to offsite structures.

C. Concept Plan

1. Geomorphic Characteristics

Key geomorphic characteristics of the existing stream and the conceptual restored stream are provided in Table 6. Proposed layout of the restored stream is shown in Figure E-3. The proposed restoration will reduce average bankfull width, increase bankfull mean depth, and decrease width/depth ratio. The increase in the depth and occurrence of pools will improve stream habitat. A key improvement is an increase in floodprone width which will greatly reduce shear stress and sediment transport for discharges greater than bankfull. Meander geometry is greatly improved. Pool spacing and radii of curvature are adjusted to stable dimensions.

Table 6: Reach OR-2 Existing and Proposed Geomorphic Characteristics

	Units	Existing Conditions Reach OR-2	Proposed Conditions Reach OR-2
Stream type		B4c	C4
Riffle bankfull width	feet	51.3	35.2
Riffle bankfull mean depth	feet	1.80	2.37
Width/depth ratio		29.1	14.9
Riffle bankfull area	$feet^2$	92.1	83.3
Maximum riffle depth	feet	2.8	3.25
Mean floodprone width	feet	90.3	153
Entrenchment ratio		1.82	4.35
Mean radius of curvature to bankfull width		3.0	3.9
Mean bankfull slope		0.0052	0.0054
Stream sinuosity		1.17	1.20

2. Planform

To minimize disturbances to existing forested areas, the planform for the restored stream remains within the valley and disturbed areas created by the existing stream. There are several locations where the new stream will require excavation beyond the bank lines of the existing channel, however, impacts are minimal because the areas are unstable. Tight meander curves are replaced by looser and shorter curves. This will reduce stress and bank retreat.

Pool-to-pool spacing and meander wavelength are evaluated in terms of the ratio to channel width. Typically, pool-to-pool spacing varies with average values of five to seven channel widths, and with most observations falling between three to nine channel widths (Keller and Melhorn, 1978).

Features of the planform for Reach OR-2 are summarized in Table 7. Curve 2 (from the downstream end) is too long (over eleven channel widths), but the extra length was necessary to avoid large areas of tree disturbance. Under existing conditions, the stream has meandered widely off-course due to flow interference with a large outfall structure. There are three structures installed through the curve to ensure stability after construction. Further adjustments will be made during final design to reduce the overall curve length of Curve 2.

Table 7: Reach OR-2 Riffle-pool Spacing

Station	Point[7]	Curve	Segment Length (feet)	Ratio of Pool-to-pool Spacing to Bankfull Width	Ratio of Meander Length to Bankfull Width
18+99.28	POB		4.57		
18+94.71	PC	7	188.12	7.55	13.18
17+06.59	PT		106.86		
15+99.73	PC	6	74.77	5.63	12.72
15+24.96	PT		115.16		
14+09.80	PC	5	145.70	7.09	15.07

[7] Table Notes:

a) Stations numbered from downstream to upstream.

b) POB – point of beginning; PC – Point of Curvature (upstream start of curve – start of Run/Pool/Glide sequence); PT – Point of Tangency (upstream start of straight section).

c) Pool-to-pool spacing measured from start of Run/Pool segment at PC to next PC downstream.

d) Meander wavelength measured from start of Run/Pool segment at PC to second PC downstream. .

Table 7: Reach OR-2 Riffle-pool Spacing					
Station	**Point[7]**	**Curve**	**Segment Length (feet)**	**Ratio of Pool-to-pool Spacing to Bankfull Width**	**Ratio of Meander Length to Bankfull Width**
12+64.10	PT		91.54		
11+72.56	PC	4	170.25	7.98	12.94
10+02.31	PT		115.09		
8+87.22	PC	3	100.61	4.97	16.63
7+86.61	PT		81.54		
7+05.07	PC	2	258.80	11.67	
4+46.27	PT		131.54		
3+14.73	PC	1	123.21		
1+91.52	PT		191.52		
0+00.00	POE				

3. Structures

There are seven cross-vanes, one in each meander curve. There are two J-hooks in Bend 2 (bends are numbered 1-7 from downstream to upstream), which replaces the tight bend near the 60-inch storm sewer outfall. There are J-hooks in Bends 4, 5, and 7. Detailed design of rock structures will be performed in later design tasks.

4. Planting Plan

Disturbed areas adjacent to the stream will be replanted with a mixture of native riparian area trees and shrubs appropriate for forested conditions. Upland areas disturbed during construction will be replanted with native upland species appropriate for the location within forested areas. Species selections will be reviewed with NPS to ensure compatibility with NPS goals and local habitats. During construction, attempts will be made to salvage large trees that cannot be avoided and replant the trees in disturbed areas.

5. Stormwater Retrofit

Conceptual stormwater retrofits are shown in Figure E-4. The strategy behind conceptual stormwater improvements is to create opportunities for trash collection at outfalls, a settling pool for large sediment, and then opportunities for stormwater to infiltrate, thereby reducing stormwater peaks and augmenting baseflow. Proposed stormwater concepts include the following elements:

- **Outfall and storm sewer removal:** Outfalls will be removed from the stream. Storm sewers will be removed from the stream to a point back in the floodplain that will be determined during the final design. The final location will be selected on the basis of hydraulic grade and avoidance of disturbance to forested areas.
- **Trash separation/sediment forebay:** Trash collection and sediment forebay areas will be installed to trap storm sewer-borne trash and debris. Trash removal is a critical issue to improving the quality of Oxon Run. Efforts should start with an education program to discourage litter, but given the observed trash load, more active efforts will be required. Forebays will require maintenance and cleanout to remove litter.
- **Bio-swale:** To minimize disturbances to existing forested areas, the Service recommends installing infiltration trenches augmented with bioretention materials and plantings that will filter and treat water quality. Typical bio-swales provides 30-80 percent pollutant removal–including decreases in total suspended solids, total phosphorous, total nitrogen, floating trash, heavy metals, biological oxygen demand, bacteria, greases, oils, and turbidity. Swales will be sized in accordance with stormwater loading to maintain minimum velocities during scour events. Depressions and sills will be installed to create retention areas for long-term infiltration into the floodplain. Placement of swales will be routed to avoid significant trees.
- **Wetland creation:** There is room for creation of a small, permanently flooded wetland in the area south of Bend 2 without disturbing standing trees. A wetland could provide additional treatment for storm flow from the Valley Terrace storm sewer. Other wet areas can be created by spreading flow from the bioswales through spreaders to create shallow sheet flow.
- **Braided channel outfall:** Outflow from the swale system will be routed through distributary channels that will spread flow across the floodplain and into Oxon Run. Flow velocities will be maintained at non-eroding velocities and the channels will provide further opportunities for infiltration. Channels will be lined with small stone and logs salvaged during construction will be used to create steps and pools.

6. Floodplain Impacts

The Service evaluated floodplain impacts by developing an existing conditions and proposed conditions HEC-RAS model for the FEMA 100-year return period discharge. The topographic survey prepared by the Service does not extend to the limits of the 100-year floodplain for existing or proposed conditions, so the limits could not be accurately mapped. The floodplain limits for the existing and proposed 100-year floodplain are similar, but additional survey will be required to accurately map floodplain limits, Review of flood elevations shows a modest decrease in water surface elevations for 10-, 50-, and 100-year floods. There is an increase for the 500-year flood elevations.

Because the water surface elevations are similar for existing and proposed conditions, it is concluded that a feasible stream restoration design can be produced in final design that will satisfy floodplain management regulations.

7. Hydraulic Validation

The Service developed a HEC-RAS model for proposed conditions. The model was run for discharges of one quarter bankfull, one half bankfull, bankfull, twice bankfull, and four times bankfull. The Service examined water surface profiles for the bankfull discharge and found that the restored stream produced depths and water surface slopes consistent with the proposed morphological parameters listed in Appendix B.

Shear Stress

The model results were evaluated for areas of high shear stress. Except for isolated areas at the head of riffles, shear stresses were less than 1.0 pound per square foot (lb/ft^2),[8] indicating that the channel banks will be stable from shear stresses after construction. Riffle crest controls will be designed to resist the higher shear stresses present at the head of riffles. Average, minimum, and maximum values of bankfull shear stress for channel features (developed form HEC-RAS analysis) are listed in Table 8.

Sediment Transport

Table 8 also lists the critical sediment size, which is largest representative particle size that can be moved on the riffles under the average applied shear stress at bankfull discharge. Critical sediment size is calculated by rearranging Shield's equation to solve for sediment size:

$$d_c = \tau_b / (\theta_c \, g \, (\rho_s - \rho)) \qquad (4)$$

where:

- d_c is the critical sediment size;
- τ_b is the total boundary shear stress (the average shear stress at bankfull is used in Table 8);
- θ_c is the dimensionless critical shear stress (Shield's parameter);
- g is gravitational acceleration;
- ρ_s is the particle density (2.65 times the density of water); and
- ρ is the density of water

Shield's parameter (θ_c) reflects the ratio at the threshold of movement between shear forces that act to overturn a particle and the weight forces of a particle that resist movement. Measured values of Shield's parameter vary with the grain size distribution, hydraulic conditions, and packing of bed materials. A value of 0.048 reflects a general value for stable gravel-bed rivers. Stream gravels placed after construction of a stream restoration project do not possess the sorting and imbrication of hydraulically transported gravels. A value of 0.032 reflects the somewhat looser material placed after construction. Table 8 lists the critical sediment size for $\theta_c = 0.032$ and for $\theta_c = 0.048$.

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[8] The shear value of 1.0 lb/ft^2 serves as an effective threshold value for evaluating stream restoration projects. Newly installed bioengineering and established areas of unmowed grass can withstand shears of 1.0 lb/ft^2. Established bioengineering and trees can withstand much higher shear stresses after a few years of growth (Schiechtl and Stern, 1996).

Table 8: Proposed Shear Stress Conditions at Bankfull Discharge – Reach OR-2

Channel Feature	Total Shear Stress at Bankfull Discharge (lbs/ft^2)			Critical Sediment Size (mm)	
	Minimum	Maximum	Average	$\theta_c = 0.032$	$\theta_c = 0.048$
Riffle	0.39	1.48	0.82	76	51
Run	0.32	0.77	0.47	43	29
Pool	0.12	0.31	0.19	18	12
Glide	0.12	0.34	0.22	20	13

The largest particle size found in the bar sample for Oxon Reach 2 was 40 mm. Because bars are built by alluvial transport, the bar sample reflects the size distribution of materials transported by the stream. Table 8 shows that the restored stream will be able to transport material that is currently in transport in Oxon Run Reach 2.

Initially after construction, the sediment making up the channel bed will have been disturbed by construction and will not have much resistance to movement. This is reflected by setting $\theta_c = 0.032$. Because of the loose bed substrate, the restored stream will have excess shear immediately after construction (*i.e.*, the stream has a capacity to transport a particle size of 76 mm). As the gravels are sorted by transport, the resistance of individual particles to movement increases as particles become imbricated into the bed, or hidden by larger particle sizes. Setting $\theta_c = 0.048$ reflects the increased resistance to movement. The critical sediment size decreases with larger dimensionless critical shear stress, reflecting the increased resistance to movement.

During the critical period immediately after construction, the potential for channel degradation and widening created by excess shear is controlled by the use of in-stream structures (*e.g.,* cross-vanes, J-hooks, and riffle crest controls). Over time, the importance of the structures in maintaining the channel form will decline as vegetation stabilizes channel banks and as sediment sorts and becomes imbricated. After the bed has sorted and stabilized, the largest particle size moved by bankfull discharge is 51 mm, which compares favorably with the largest particle from the bar sample (40 mm).

Summary

Analysis of the proposed design using HEC-RAS shows that the ranges of hydraulic and sediment transport conditions are generally within target ranges. There are some isolated areas where shear forces may be higher than desirable. These areas will be adjusted in future design revisions. However, the hydraulic analysis demonstrates the concept designs are acceptable and that final designs can produce stable streams.

8. Design Tradeoffs

Minimizing impacts to existing tree stands and minimizing excavation limited the flexibility for alignments for the restored stream. Only a small increase in stream sinuosity was achieved (from 1.17 to 1.20). Higher stream sinuosity would require impacts to large tree stands and excavation of the upper floodplain. The Service evaluated alternate alignments that increased stream sinuosity, but found that they resulted in excessive earthwork requirements or created large disturbances to forest stands.

Routing the stream around the large curve created by erosion at the 60-inch outfall resulted in the creation of a long meander curve (Bend 2) that incorporates two J-hooks and a cross-vane. This curve cannot be shortened without decreasing stream length and pushing the stream to the south (further into areas of established trees), or by pulling Bend 3 north and decreasing stream length.

9. Alternate Design Elements

Stormwater is a major source of trash. Trash separators at outfalls will require cleanout and maintenance, a long-term maintenance cost. Trash could be separated from stormwater further up-system using in-line trash separators. Several devices are available in the District area and have been installed by local municipalities. Typically these structures are installed at an existing manhole. Mechanical separation, driven by the action of flowing water, separates trash and collects it a central holding tank. Frequent cleanout (*i.e.*, several times a year) is required using either vacuum trucks or trucks equipped with a winch. Other alternatives that the District might consider are replacing inlets with grates that would block entry of floatables.

10. Cost Estimate

Conceptual level cost estimates for Oxon Run Reach OR-2 are included in Appendix G. Estimated Costs for construction of stream restoration for Reach OR-2 are $534,400 or $230 per linear foot. Design and construction management costs are $130,000 or $72 per linear foot. Stormwater management retrofit for four storm sewers in Reach OR-2 is estimated to cost $81,700 for construction and $24,600 for design and construction management. Total stormwater retrofit costs are $106,300 or about $26,600 per storm sewer.

D. Implications for Restoration of Natural Stream Portions of Oxon Run

A feasible concept plan was developed for Reach OR-2 that met restoration objectives. Additional work will be required by WASA to address leaky sanitary sewers and by Prince George's County to improve the quality of water entering the District.

Reach OR-2 possesses a wide meandering stream corridor. The Service was able to design stream restoration for Reach OR-2 that avoided large areas of tree disturbance by routing the stream alignment through the existing stream valley. Other reaches within the NPS park lands are straight, so it may not be possible to develop a stream alignment that does not create tree impacts in the straight reaches. This issue will require discussions with NPS when design of Reaches OR-3 to OR-8 occurs.

IV. CONCEPT PLANS - OXON RUN REACH 9B

A. DESCRIPTION

1. Location/Physiography

Oxon Run Reach 9B (OR-9B) is located within a parcel of land bounded by Mississippi Avenue to the north, Valley Avenue to the south, Wheeler Road to the east, and 4th Street to the west (Figure F-1 in Appendix F). Reach OR-9B is 2,520 feet long and comprises a portion of the concrete channel that runs from 13th Street to South Capitol Street. The concrete channel is trapezoidal in shape, with a bottom width of 50 feet, a top width of 75 feet, and side-slope of 2H:1V. The concrete channel was designed to contain the 15-year storm and to reduce flooding risk (District Department of Environmental Services 1979).

The parcel of land bounded by Mississippi Avenue, Valley Avenue, 4th Street, and Wheeler Road, with the exception of a small out parcel at the corner of Wheeler Road and Mississippi Avenue was originally NPS land. The parcel was transferred to the management of the District. Over time, the District developed portions of the parcel. Currently, there are two schools (Simon Elementary School and Hart Middle School), a swimming pool, a tennis center and associated buildings on the Mississippi Avenue frontage. The remainder of the parcel is undeveloped and is part of the Oxon Run Park managed by DPR. There are small, isolated stands of trees, but most of the park land is open grassland. There are paved paths that run through the park and a lighted baseball diamond near 4th Street.

The concrete channel offers no habitat value. Stream flow is spread into shallow flow. The concrete channel is open and provides no cover. The direct exposure to sunlight during summer months creates high temperature impacts.

The Service believes, from the topographic layout of the park area, that there has been significant filling and grading within the floodplain. Oxon Run appears to be pinched between two fill areas in the upstream area below Wheeler Road. Both 4th Street and Wheeler Road appear to have been placed on fill that blocks flow along the floodplain. The baseball diamond may have been graded low to reduce flooding at Simon Elementary School (corner of 4th Street and Wheeler Road).

2. Utilities

Storm Sewer Outfalls

There are five storm sewers that discharge into the concrete channel (Figure F-2). Two drain the area above Mississippi Avenue, two drain the area above Valley Avenue, and the fifth one drains Wheeler Road.

Sanitary Sewers

The Oxon Run Collectors continue their run along Oxon Run through Reach OR-9B. The 42-inch sanitary sewer runs along the north edge of the concrete channel and was constructed in a joint project at the same time as the concrete channel (1978-1979). Review of as-built plans provided by WASA (Purdum & Jeschke Engineering 1979) indicate that the 42-inch line sanitary sewer was generally placed at least six inches below the bottom of the concrete channel and that the concrete channel is six inches thick.

The 24-inch sanitary sewer runs south of the concrete channel. The 24-inch sanitary sewer is set back from the concrete channel and is about 70 feet from the edge of the concrete channel where it crosses into the park from Wheeler Road. The course of the 24-inch sanitary sewer first diverges from the concrete channel reaching a maximum separation of 150 feet about 450 feet from Wheeler Road. Then, the course of the 24-inch sanitary sewer converges with the concrete channel reaching a separation distance of less than 20 feet opposite 9th Street. From 9th Street to 4th Street, the course of the 24-inch sanitary sewer is close to the concrete channel. There is one cross connection between the 24-inch and 42-inch sanitary sewer that passes beneath the concrete channel.

Water Mains

The as-built plans (Purdum & Jeschke Engineering 1979) for the concrete channel indicate the presence of a 20-inch water line located south of the 24-inch sanitary sewer. The Service has not determined if this line is still present. The proposed design does not conflict with the location of the water main, but further investigations are required to ensure that no other water mains are present or that the one shown in the 1979 as-built plans has not been relocated.

Bridges

The District recently completed rehabilitation of both the Wheeler Road and 4th Street Bridges over Oxon Run. Comparison of the low chord elevation (*i.e.*, the elevation of the bottom of the bridge deck) with FEMA 100-year flood elevations indicates that the low chords have been set to provide one-foot clearance above the 100-year flood. Attempts to obtain bridge hydraulic studies from the District Department of Transportation have not been successful to date.

In addition to the highway bridges, there is a foot-bridge that crosses the concrete channel about midway between Wheeler Road and 4th Street.

B. Design Assumptions

The primary goals of the stream restoration for Reach OR-9B are to develop a stream capable of maintaining a stable, self-maintaining state and to improve stream habitat. In the absence of other controls, there are a number of stream planforms that could accomplish these objectives. There are a number of additional concerns in Reach OR-9B, however, that the proposed stream restoration must accommodate:

- **Floodplain management goals:** The 100-year floodplain is located within the boundaries of the park, but the 100-year floodplain currently impinges on the Simon Elementary School. Additionally, the Service has received anecdotal reports of flooding problems in the vicinity. Concept stream restoration plans for Reach OR-9B are not feasible if the risk of flooding to structures along Mississippi Avenue is increased.

- **Highway bridges:** The District Department of Transportation is in the process of completing rehabilitation projects for the 4th Street and Wheeler Road Bridges.

Low chord elevations for the bridges appear to have been set to provide one foot of clearance above the level of the FEMA 100-year floodplain elevations. Concept restoration plans that require adjustments in bridge low chord elevations (*i.e.*, raising the level of the stream) are not considered feasible because of cost involved to modify or relocate bridges.

- **Sanitary sewers:** The paths of the two Oxon Run Collectors create a narrow corridor for the stream. There is not sufficient space within the corridor to provide room to increase stream sinuosity and therefore, proposed alignments must cross over existing sanitary sewers.

  The south side of the park, where the 24-inch sanitary sewer is located, possesses ground that is much higher than the level of the stream. There are broad areas of flat ground to the north of the concrete channel, beyond the limits of the 42-inch sanitary sewer. Therefore, crossing the 42-inch sanitary sewer offers better opportunities for relocating the stream.

  The top of the 42-inch sanitary sewer is generally about one foot below the current surface elevation of the bottom of the concrete channel. Pools in the restored stream will extend below the top of the 42-inch sanitary sewer, so crossings of the 42-inch sanitary sewer must occur in riffles. It is anticipated that concrete encasements will be required for the 42-inch sanitary sewer where crossings occur. Rock may be placed above the encasements as grade controls to prevent exposure. Stream grade control structures will be placed on the downstream side of all stream crossings to ensure that no headcuts expose sanitary sewers.

- **Earthwork costs:** Excavation costs could be a large factor in total construction costs. Therefore, plan development worked to minimize the total amount of excavation.

- **Removal of concrete channel:** It is assumed that the concrete channel will be removed. Portions of the broken concrete might be employed as buried footers, but off-site disposal will be required for a majority of the concrete.

- **Recreational uses in park:** DPR expressed interest in the stream restoration as a means of improving park aesthetics. The only developed use in this section of Oxon Run Park is the baseball diamond located adjacent to Simon Elementary School and 4th Street. The Service attempted to develop concept plans that avoid disturbance to the baseball diamond, but we were unable to achieve this goal due as explained below.

- **Tree stands:** There are only scattered patches of mature tree stands in the park. Because it will take many years to re-vegetate areas of the park with mature trees, concept plans avoided or minimized disturbance to areas of standing trees.

C. Concept Plan

1. Geomorphic Characteristics

Key geomorphic characteristics of the existing channel and the conceptual restored stream are listed in Table 9 and shown in Figure F-3. The proposed restoration will reduce average bankfull width, increase bankfull mean depth, and decrease width/depth ratio. The increase in the depth and occurrence of pools will improve stream habitat. The variety of stream characteristics is greatly improved.

Table 9: Reach OR-9B Existing and Proposed Geomorphic Characteristics			
	Units	**Existing Conditions Reach OR-9B**	**Conceptual Stream Restoration Reach OR-2**
Stream type		Concrete Channel	C4
Riffle bankfull width	feet	56.7	35.2
Riffle bankfull mean depth	feet	1.67	2.37
Width/depth ratio		33.5	14.9
Cross section area at bankfull discharge	$feet^2$	83.4	83.3
Maximum riffle depth	feet	1.67	3.25
Mean floodprone width	feet	63.4	153
Entrenchment ratio		1.12	4.35
Mean radius of curvature to bankfull width		----	3.9
Average stream slope	upper	0.0065	0.0062
	lower	0.0046	0.0044
Stream sinuosity		1.08	1.20

2. Planform and Profile

Development of a feasible planform and profile for Reach OR-9B proved to be a complex undertaking due to site conditions. The proposed planform shown in Figure F-3 is the result of the following design considerations:

- **Vertical grade conflicts with sanitary sewers**: Grade conflicts with sanitary sewers required that stream crossings over sanitary sewers take place at riffles, and that pools could not be located in the vicinity of sanitary sewers. Thus, the location of the alignment was constrained in many locations. For example, Bend 8 (meander bends are numbered 1 – 10 from downstream to upstream) cannot be moved further north because the pool would then conflict with the 42-inch sanitary sewer. Bends 2 and 5 had to be placed so that both the heads and tails of pools were on the same side of the 42-inch sanitary sewer.
- **Orientation and location of highway bridges:** To minimize potential for bridge scour and to produce good flow transitions through the bridges, the proposed

stream restoration was aligned to approach and exit the bridge openings at right angles.

The existing stream, valley, and sanitary sewer corridor make a bend to the left below the Wheeler Road Bridge and a bend to the right just before the 4th Street Bridge. Because of the valley and sanitary sewer alignments, the alignment of the restored stream is forced to follow the same bends.

- **Floodplain management requirements**: The 100-year floodplain impinges on the Simon Elementary School. Any increase in flood elevations within the lower reach area was considered unacceptable because of potential increased flood risk to the school. In the upper reach, increases in flood elevation are contained within a tight valley and are limited in extent, but increases in the 100-year flood elevation would reduce freeboard during the 100-year flood at the Wheeler Road Bridge.

  Hydraulic analyses prepared with HEC-RAS showed that flow in the portion of the existing concrete channel below the Wheeler Road Bridge is supercritical under flood conditions because of the channel steepness, straightness, and low hydraulic roughness (*i.e.*, concrete surface). Replacing the concrete channel with a meandering, natural stream causes sub-critical flow that is deeper and less swift. Unfortunately, the change in flow regime for the proposed restoration also creates unacceptable increases in water surface elevations unless measures are taken to compensate for the increase. Additional conveyance (flow area) was required to reduce water surface elevations to acceptable levels. The additional conveyance was created by curving the alignment to the south and grading back the southern slope. Moving the alignment to the north, which would have required less excavation, was not an option because it would have impacted the tennis center.

- **Change in valley grade:** The valley slope is not uniform. The valley slope in the portion of Reach OR-9B between Wheeler Road and the foot-bridge (upper reach) is steeper than the portion of the reach between the foot-bridge and 4th Street (lower reach). Maintaining a constant bankfull slope through the entire reach aggravated vertical conflicts with sanitary sewers, and increased fill and flood elevations in the lower reach. Thus, two channel slopes are used for the restored stream; a steeper slope in the upper reach and a shallower slope in the lower reach.

- **Excavation quantities**: Excavation quantities are high and increase construction costs. Large amounts of excavation are required to reduce flood levels in the upper reach and to excavate the stream on the floodplain in the lower reach where no stream currently exists.

  A balanced earthwork job can still be achieved by disposal of fill within the park. Figure F-3 shows areas where fill can be placed and not increase flood elevations. Some fill can be placed in areas where the concrete channel is removed. Fill can also be placed outside the limits of the 100-year floodplain or on the floodplain fringes to augment levees already in place.

- **Baseball diamond**: The proposed stream alignment results in intrusion into the right side of the baseball diamond. The baseball diamond could not be avoided because avoidance of vertical conflicts with the 42-inch sanitary sewer required that the pool features of Bend 2 be placed north of the 42-inch sanitary sewer. The direction and orientation of Bend 2 was somewhat fixed by the location of Bend 1 and the tie-in of Bend 1 to the 4th Street Bridge.

Features of the planform are summarized in Table 10. Pool-to-pool spacing and meander wavelength are given in terms of the ratio to channel width. Pool-to-pool spacing varies with average values of five to seven channel widths, and with most observations falling between three to nine channel widths (Keller and Melhorn, 1978).

Table 10: Reach OR-9B Riffle-pool Spacing

Station	Point[9]	Curve	Segment Length (feet)	Ratio of Pool-to-pool Spacing to Bankfull Width	Ratio of Meander Length to Bankfull Width
26+64.96	POE		111.83		
25+53.13	PC	10	99.26	6.29	12.87
24+53.87	PT		128.03		
23+25.84	PC	9	88.19	6.58	13.88
22+37.65	PT		142.38		
20+95.27	PC	8	88.77	7.30	13.81
20+06.50	PT		166.75		
18+39.75	PC	7	92.13	6.52	10.12
17+47.62	PT		124.92		
16+22.70	PC	6	180.76	9.08	18.92
14+41.94	PT		129.51		

[9] Table Notes:

a) Stations numbered from downstream to upstream.

b) POB – point of beginning; PC – Point of Curvature (upstream start of curve – start of Run/Pool/Glide sequence); PT – Point of Tangency (upstream start of straight section).

c) Pool-to-pool spacing measured from start of Run/Pool segment at PC to next PC downstream.

d) Meander wavelength measured from start of Run/Pool segment at PC to second PC downstream.

Table 10: Reach OR-9B Riffle-pool Spacing					
Station	**Point[9]**	**Curve**	**Segment Length (feet)**	**Ratio of Pool-to-pool Spacing to Bankfull Width**	**Ratio of Meander Length to Bankfull Width**
13+12.43	PC	5	247.59	9.84	16.10
10+64.84	PT		102.15		
9+62.69	PC	4	130.77	6.26	13.51
8+31.92	PT		92.40		
7+39.52	PC	3	125.18	7.25	14.68
6+14.34	PT		123.06		
4+91.28	PC	2	202.68	7.44	
2+88.60	PT		84.48		
2+04.12	PC	1	145.30		
0+58.82	PT		58.82		
0+00.00	POB				

3. Structures

There are ten cross-vanes, one in each meander curve. Note that a cross-vane in Bend 1 will provide good orientation of flow approaching the 4th Street Bridge. The cross-vane in Bend 10 will provide grade control for the transition below the Wheeler Road Bridge. There are J-hooks in Bends 1 and 6. Cross-vanes are placed below the sanitary sewer crossings at the head of Bends 2 and 5.

4. Channel Substrate

The natural reaches of Oxon Run possess an active gravel bed. The restored stream will require supplied stream gravel roughly matching the size distribution of upstream areas.

5. Stormwater Retrofit

Conceptual stormwater retrofits are shown in Figure F-4. The strategy behind conceptual stormwater improvements is to create opportunities for trash collection at outfalls, a settling pool for large sediment, and then opportunities for stormwater treatment and infiltration, thereby reducing stormwater peaks and augmenting base flow. DPR expressed an interest in incorporating water features into the landscape such as ponds and wetland. The open areas of the park create ample opportunities for water features that can be incorporated into stormwater treatment facilities. Proposed stormwater concepts include the following elements:

- **Outfall and storm sewer removal:** Outfalls will be removed from the channel. Storm sewers will be removed from the stream to a point back in the floodplain that will be determined during the final design. The final location will be selected on the basis of hydraulic grade and surrounding topography.
- **Trash separation/sediment forebay:** Trash collection and sediment forebay areas will be installed at the end of storm sewers to trap storm sewer borne trash and debris. Trash removal is a critical issue to improving the quality of Oxon Run. Forebays will require maintenance and cleanout to remove litter.
- **Wetland creation:** Several small wetlands will be created to treat stormwater. The ponds will be wet detention ponds.
- **Bio-swales:** Water will be routed from the forebays to the wetlands through bioswales, ditches that allow infiltration and provide water quality treatment. Typical bio-swales provides 30-80 percent pollutant removal, including decreases in total suspended solids, total phosphorous, total nitrogen, floating trash, heavy metals, biological oxygen demand, bacteria, greases, oils, and turbidity. Swales will be sized in accordance with stormwater loading to maintain minimum velocities during scour events. Depressions and sills will be created to create retention areas for long-term infiltration into the floodplain.
- **Bird pond:** There is room on the floodplain below the swimming pool to create a large pond with permanent open water. The perimeter of the pond should be landscaped with vegetation to discourage geese. Hummocks can be left in the middle of the pond to create nesting areas. The pond might also be used to enhance environmental education programs in the local schools.
- **Braided channel outfall:** Outflow from the wetlands will be routed through distributary channels that will spread flow across the floodplain and into Oxon Run. Flow velocities will be maintained at non-eroding velocities and the channels will provide further opportunities for infiltration. Channels will be lined with small stone and logs will be used to create steps and pools.

6. Planting Plan

Cost estimates include costs for planting a riparian buffer, stormwater ponds, the larger bird pond, and bioswales. A riparian buffer will be planted adjacent to the stream channel using native trees and shrubs. Disturbed areas away from the stream will be replanted as grassed lawns or as flower meadows in keeping with direction from DPR. Stormwater ponds and bioswales will be planted with wetland plants to encourage stormwater treatment. The bird pond will be planted along the edges to discourage resident geese.

7. Floodplain Impacts

The Service evaluated floodplain impacts by developing HEC-RAS models of existing and proposed conditions. The proposed grading plan creates minor increases in flood elevations that are within acceptable levels. Increases in flood elevations are higher for more frequent floods (*i.e.*, 10-year and 50-year return period) because the restored stream is designed to carry a bankfull flow with a return period of less than 2 years rather than the 15-year return period discharge. There are minor differences in the extent and elevation of the 100-year flood. Elevations for the 500-year flood are less for proposed conditions than for existing conditions.

Analysis of floodplain impacts demonstrates that a feasible design can be produced by grading adjustments in the floodplain. As the 100-year floodplain abuts the Simon Elementary School and Hart Middle Schools, a careful evaluation of the floodplain in this area will be required for final design.

8. Hydraulic Validation

The Service developed a HEC-RAS model for proposed conditions. The model was run for discharges of one quarter bankfull, one half bankfull, bankfull, twice bankfull, and four times bankfull. The Service examined water surface profiles for the bankfull discharge and found that the restored stream produced depths and water surface slopes consistent with the proposed morphological parameters listed in Appendix B.

Shear Stress

The model results were evaluated for areas of high shear stress. Except for isolated areas at the head of riffles, shear stresses were less than 1.0 pound per square foot (lb/ft^2), indicating that the channel banks will be stable from shear stresses after construction. Riffle crest controls will be designed to resist the higher shear stresses present at the head of riffles. Average, minimum, and maximum values of bankfull shear stress for channel features (developed form HEC-RAS analysis) are listed in Table 11.

Sediment Transport

Table11 also lists the critical sediment size, which is largest representative particle size that can be moved on the riffles under the average applied shear stress at bankfull discharge. Shield's parameter reflects the ratio at the threshold of movement between shear forces that act to overturn a particle and the weight forces of a particle that resist movement. Measured values of Shield's parameter vary with the grain size distribution, hydraulic conditions, and packing of bed materials. A value of 0.048 reflects a general value for stable gravel-bed rivers. Stream gravels placed after construction of a stream restoration project do not possess the sorting and imbrication of hydraulically transported gravels. A value of 0.032 reflects the somewhat looser material placed after construction. Table 11 lists the critical sediment size for $\theta_c = 0.032$ and for $\theta_c = 0.048$.

Because Reach 9 is lined with concrete, field sampling of sediment properties was not possible. During construction it will be necessary to import gravel to line the restored stream channel. The properties of the supplied sediment will be determined during further design efforts, but likely the objective will be to provide sediment that reflects a transition from the sediment transported into the reach from Reaches 1-8 and the sediment found in Reach 10.

The largest particle size found in the bar sample for Oxon Reach 2 was 40 mm. Immediately after construction the placed gravel in the restored stream channel will be loose and poorly sorted, leading to low resistance to particle movement. A dimensionless critical shear stress value of 0.032 is used to reflect loose gravel conditions that will exist immediately after construction. Under immediate post-construction conditions, the channel will have excess shear (*i.e.*, the stream has a capacity to transport a particle size of 75 mm). As the gravels are sorted by transport, the resistance of individual particles to movement increases as particles become imbricated into the bed, or hidden by larger particle sizes. Setting $\theta_c = 0.048$ reflects the increased resistance to movement. The critical sediment size decreases with larger dimensionless critical shear stress, reflecting increased resistance to movement. During the critical period immediately after construction, the potential for channel degradation and widening created by excess shear is controlled by the use of in-stream structures (*e.g.*, cross-vanes, J-hooks, and riffle crest controls). Over time, the importance of the structures in maintaining the channel form will decline as vegetation stabilizes channel banks and as sediment sorts and becomes imbricated.

After the bed has sorted and stabilized, the largest particle size moved by bankfull discharge is 50 mm, which compares favorably with the largest particle from the bar sample (40 mm). Table 11 shows that the restored stream will be able to transport material that is currently in transport from Oxon Run Reach 2. Post restoration sediment capability for Reach OR-9B is similar to Reach OR-2.

Table 11: Proposed Shear Stress Conditions at Bankfull Discharge – Reach OR-9B

Channel Feature	**Total Shear Stress at Bankfull Discharge (lbs/ft^2)**			**Critical Sediment Size (mm)**	
	Minimum	**Maximum**	**Average**	$\theta_c = 0.032$	$\theta_c = 0.048$
Riffle	0.41	1.46	0.81	75	50
Run	0.27	0.78	0.50	46	31
Pool	0.12	0.34	0.23	21	14
Glide	0.10	0.66	0.23	21	14

Summary

Analysis of the proposed design using HEC-RAS shows that the ranges of hydraulic and sediment transport conditions are generally within target ranges. There are some isolated areas where shear forces may be higher than desirable. These areas will be adjusted in future design revisions. However, the hydraulic analysis demonstrates the concept designs are acceptable and that final designs can produce stable streams.

9. Alternate Design Elements

- **Pedestrian/bicycle bridges:** It is likely that DPR will desire to replace the pedestrian bridge after stream restoration. The restoration plan can incorporate low-water crossings or fords, but safety and liability concerns will likely require that bridges are constructed with the low-chord above the level of the 100-year flood. The cost estimate for the stream restoration does not include costs for bridge replacement.

- **Diversion channel to pond:** A diversion from Oxon Run can be constructed that would divert a small amount of water into the bird pond. This would provide long-term, low-level, flushing of the pond.
- **Landscaping:** Current cost estimates assume creation of a riparian forest buffer and stormwater wetlands. No costs are included for additional planting, such as might be required for landscaping the park.
- **Creative use of fill:** The excess fill can be used to create recreational features such as small mounds for a children's park or for stream overlooks.
- **Alternate planforms:** The Service developed and evaluated several alternate planforms. Some of the alternates were straighter and designed to stay within the corridor created by the Oxon Run Collectors. These were rejected because they resulted in low stream sinuosity. Some of the alternates made large sweeps into the floodplains adjacent to the Simon School and swimming pool. Theywere rejected because they created larger amounts of excavation.
- **Trash separators:** As with Reach OR-2, trash separators at outfalls will require cleanout and maintenance, a long-term on-going cost. Trash could be separated from stormwater further up-system using in-line trash separators. Several devices are available in the District area and have been installed by local municipalities. Typically these structures are installed at an existing manhole. Mechanical separation, driven by the action of flowing water, separates trash and collects it in a central holding tank. Frequent cleanout (*i.e.*, several times a year) is required using either vacuum trucks or trucks equipped with a winch. Alternately, the District might consider measures to trap trash at inlets before it enters stormwater sewers.

10. Cost Estimate

Conceptual level cost estimates for Oxon Run Reach OR-9B are included in Appendix G. Estimated Costs for construction of stream restoration for Reach OR-9B are $807,800 or $303 per linear foot. Design and construction management costs are $232,600 or $87 per linear foot. Removal of the concrete channel is estimated to cost $224,000 or $84 per linear foot. Stormwater management retrofit for five storm sewers is estimated to cost $206,500 for construction and $62,000 for design and construction management. Total stormwater retrofit costs are $268,500 or about $53,700 per storm sewer.

Cost estimates are higher for Reach OR-9B then for Reach OR-2 due to extra excavation costs to remove fill from the floodplain, costs for removing the concrete channel, use of larger stormwater ponds, and construction of the bird pond.

D. Implications for Restoration of Remaining Portions of Concrete Channels

Removal of the concrete channels from Oxon Run Park and replacement with a restored stream will be a complex, but feasible design task. Major considerations must be given in the design process to selecting an alignment that does not conflict with existing infrastructure. Areas where structures now are subject to high flood risk may present difficult challenges. The concept plan for Reach OR-9B, however, shows that these challenges may be overcome by creative grading.

Other issues that should be examined further include:

- **Disposal and reuse of concrete channel:** Significant cost savings can be obtained if creative ideas for disposal or reuse of concrete can be implemented. Use as artificial reef material, or burial within the project area should be explored. As there are over 9,300 cubic yards of concrete comprising the channel (from 13th Street to South Capitol Street), it may be cost effective for a commercial concrete recycling company to remove the channel at reduced cost.
- **Opportunities for redevelopment of Oxon Run Park:** DPR is starting development of a master plan for the Oxon Run Park. The concept plan for Reach OR-9B demonstrates some of the design elements that can be incorporated with stream restoration to greatly enhance the value of Oxon Run Park to the community. Coordination with DPR and the community will be required to determine how the use and appearance of the park should change with implementation of the stream restoration.

V. DISCUSSION

A. COST ESTIMATES FOR RESTORING OXON RUN

The Service developed concept level cost estimates for each restoration reach. The Service extrapolated cost estimates from the representative reaches to estimate total costs for restoring the Oxon Run main stem within the District.

Cost estimates for the restoration plans are based on typical costs for constructing stream restoration projects in the Maryland and District metropolitan areas. The Service believes that there may be ways of reducing the typical "costs of doing business" through alternate contracting methods, construction supervision, construction inspection, and partnership agreements. There are also potential cost savings that may result from the scale of the project.

Per linear foot costs for restoring Oxon Run Reach OR-9B (concrete channel section) are greater than for Oxon Run Reach OR-2 for several reasons:

- Increased costs associated with removal and disposal of the concrete channel.
- Increased amount of excavation required to avoid increased risk of structure flooding.
- Increased excavation to construct shallow wetlands and large pond.

Estimated Costs for restoring Oxon Run Reach OR-2 (including design and construction management costs) are $302 per liner foot or total costs of $543,400.

Estimated Costs for restoring Oxon Run Reach OR-9B (including costs for design, construction management, and removal of the concrete channel) are $475 per liner foot or total costs of $1,264,400.

Total costs for restoring Oxon Run were estimated by extrapolating the estimated costs for the representative reaches to the entire main stem on the basis of linear feet. Total estimated costs (including design and construction management costs) for restoring the main stem of Oxon Run within the District are $6,888,888. This does not include removal of the drop structure at the Forest Heights Flood Protection Project.

Stormwater retrofit costs for the Oxon Run main stem are roughly estimated to cost $1,094,000. Cost estimates for stormwater retrofit are rough because costs vary significantly with individual site conditions and the type of retrofits employed at each site.

B. PARTNERSHIP OPPORTUNITIES

There are significant opportunities at this time to integrate restoration of the Oxon Run main stem with other projects underway in and adjacent to the stream corridor:

- DPR is developing a master plan for the Oxon Run Park. This encompasses the concrete channel section of Oxon Run that extends from 13th Street to South Capitol Street. The master plan is funded in part by the District Department of Transportation. Discussions with DPR have indicated that DPR has significant interest in incorporating stream restoration into the master plan. Indeed, restoration of Oxon Run is seen as providing great potential for improved aesthetics and park recreational opportunities.

- WASA is starting rehabilitation projects for portions of the two sanitary sewer lines that lie adjacent to Oxon Run (Oxon Run Collectors). In the fall of 2003, WASA hired a consultant to prepare feasibility studies for the portion of the Oxon Run Collectors lying between 13th Street and Southern Boulevard. The feasibility study will recommend improvements that WASA will construct in 2005.

It is recommended that DOH maintain close contact with both agencies. Both WASA and DPR have indicated willingness to make adjustments in their designs to accommodate stream restoration, but opportunities may be lost without close contact. Additionally, there may be opportunities to reduce project costs by combining efforts.

C. Additional Design Issues for Restoration of Oxon Run

The Service developed concepts plans for two representative reaches. From the Oxon Run Assessment, the Service is aware of several additional issues that did not influence the design of Reaches OR-2 and OR-9B, but will need to be addressed as designs are developed for the remainder of Oxon Run. Issues Include:

1. Magnolia Bogs

Four northern magnolia bogs are located in the park lands administered by NPS adjacent to the upper reaches of Oxon Run (Reaches OR-3 through OR-8). The NPS places great value on the bogs because they are the only ones known to exist in the NPS system (EA Engineering 1998), and because this type of coastal plain bog is nearly extinct. Urbanization had decreased the amount of groundwater flow to the bogs.

At the very least, construction of the Oxon Run stream restoration cannot create any adverse impacts to the bogs. Opportunities for improving bog hydrology through increased floodplain infiltration of storm flow should be investigated with NPS biologists as part of final design.

2. Forest Height Flood Protection Works

The Corps constructed a flood-control project in the community of Forest Heights, Maryland at the end of Oxon Run (Corps 1959). There is a grade control structure that creates a 3-foot drop in stream grade at the end of Reach OR-12. Removal of the structure will be required to allow fish passage from the Potomac to the upper reaches of Oxon Run. As the structure is part of a Corps flood protection project, coordination with the Corps will be required to gain approval for modifying the structure.

3. Environmental Hazards

There are several environmental hazards that stream restoration plans for the remainder of Oxon Run will need to address

- **Landfill**: There is an unlined landfill along the left bank of Oxon Run, downstream of South Capitol Street. The stream is currently migrating into the landfill.
- **Unexploded ordnance**: There is risk from unexploded ordinance in the vicinity of Reaches OR-3 to OR-8.
- **Contaminants:** Due to the long history of development in the watershed and alterations of the land around Oxon Run itself, there is increased risk of encountering contaminants during excavation.

VI. RECOMMENDATIONS

A. Build Consensus for Restoring Oxon Run

The Oxon Run restoration will provide benefits to the environment through improved water quality and habitat. It also offers the opportunity to be the focal point for community revitalization efforts in the areas of the District bordering the stream.

Undertaking the restoration of Oxon Run is a major effort requiring participation from all members of the community including public agencies, the general public, and legislators. The Service recommends that the DOH work to build community consensus to restore the stream. Recommended consensus building activities are:

- DOH should pursue partnership agreements with other agencies such as WASA, DPR, NPS, and the Corps to obtain funding to complete restoration design and to implement construction of the Oxon Run stream restoration.
- DOH should hold a public meeting with agencies, invited legislators and the general public to present initial concepts and to provide a forum for input and reaction from residents.

B. Comprehensive Stream Restoration Plan for Oxon Run

The concept plans demonstrate that stream restoration of Oxon Run is feasible. The Service recommends that DOH authorize the Service to undertake additional geomorphic investigations to improve the reliability of stream restoration designs and to prepare comprehensive concept designs for the entire length of Oxon Run. It is critical that the concept designs are developed at this time while WASA and DPR are undertaking their own planning efforts for the area adjacent to Oxon Run so that their designs can be coordinated with stream restoration improvements. There are also potential cost savings that can result by coordinated construction efforts.

C. Pursue Stream Restoration Efforts in Prince George's County

Oxon Run lies within the District and Prince George's County, Maryland. Significant sediment loading to Oxon Run is generated by bank erosion in Prince George's County (Brown et al. 2003). Stream restoration and bank stabilization is required in Prince George's County to improve water quality and to reduce stream impairment in the entire Oxon Run main stem.

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