Evaluation of Freshwater Aquatic Resources and Stormwater Management at U.S. Naval Submarine Base, Bangor, Washington

by Christopher W. May

Technical Memorandum
APL-UW TM 6-97
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Applied Physics Laboratory University of Washington
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"When you put your hand in a flowing stream, you touch the last of what has gone before and the first of what is yet to come..."

Leonardo di Vinci, 1518

ABSTRACT

Surface and stormwater conditions on the Naval Submarine Base (NSB), Bangor, Washington, are evaluated, and recommendations are made to improve water quality and enhance the ecological integrity of aquatic resources located on the base. NSB, Bangor, is located within the upper Hood Canal watershed, a sensitive and ecologically important area of Puget Sound. The base is the only major industrial facility on Hood Canal and as such has a unique responsibility to protect this valuable natural resource. Based on a thorough assessment of physical, chemical, and biological conditions in streams, wetlands, and lakes within the base, an integrated surface and stormwater management (SSWM) plan is developed. This plan is built around a watershed-based, resource-driven approach for protecting aquatic ecosystems from the effects of human activities. The SSWM plan includes specific recommendations for improving stormwater best management practices with the goal of reducing the quantity of stormwater runoff and improving water quality. Application of innovative techniques for managaing stormwater runoff and for nonpoint-source pollution control was a high priority. The stream protection strategy is a long-range, on-going process that will require close cooperation with local county and tribal agencies. This plan could serve as a model for other Department of Defense facilities in the Pacific Northwest region and could be adapted to other areas of the country as well.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

STUDY OBJECTIVES

The overall goals of this project were to improve the water quality and enhance the ecological integrity of aquatic resources located within the Naval Submarine Base at Bangor, Washington (NSB-Bangor). A main objective of this study was to assess the current condition of aquatic resources, especially the native salmonid populations utilizing on-base streams, wetlands, and lakes. Based on this assessment, an in-stream habitat enhancement and rehabilitation plan was developed. A second main objective of the project was to evaluate the existing stormwater management infrastructure, including structural best management practices (BMPs) and nonstructural BMPs. Special attention was given to current surface and stormwater management problems identified by personnel of the NSB-Bangor Public Works (PW) Department. Based on this evaluation, an integrated surface and stormwater management (SSWM) plan was developed. This plan is built around a watershed-based, resource-driven approach for protecting aquatic ecosystems from the impact of human activities (Schueler, 1995). This stream protection strategy is a long-range, ongoing process (Figure 1). This plan could serve as a model for other Department of Defense (DoD) facilities in the Pacific Northwest (PNW) region and could be adapted to other areas of the country as well. Application of innovative techniques for stormwater runoff and non-point-source (NPS) pollution control was a high priority.

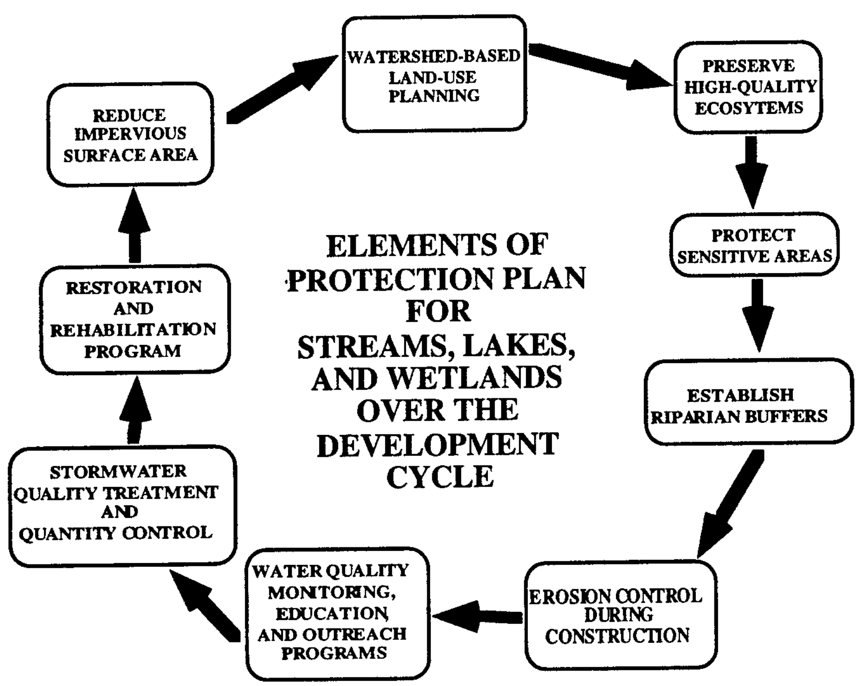


Figure 1. Key elements of a watershed-based protection strategy for aquatic resources (Schueler, 1995).

BACKGROUND

NSB-Bangor is located on a narrow portion of the Kitsap Peninsula along the eastern shore of Hood Canal (Figure 2). The base includes portions of several small-stream watersheds, along with direct drainage to Hood Canal. The base has many of the characteristics typically found in developing areas of the Pacific Northwest. As with most urbanizing areas, impervious surfaces are responsible for most of the stormwater runoff generated on the base. Urbanized areas include residential, commercial, and industrial land uses. Extensive naturally forested areas still remain within the base, and the overall density of development is still fairly low.

The base is home to the Pacific Trident Submarine Fleet (Submarine Group Nine and Submarine Squadron Seventeen) along with the Pacific Submarine Development Group, the Trident Training Facility (TTF), the Trident Refit Facility (TRF), Naval Base Seattle, an annex of the Naval Undersea Warfare Center, the Puget Sound Naval Communications Station, and the Strategic Weapons Facility Pacific (SWFPAC). Numerous industrial and commercial support facilities, as well as several recreational and residential areas, are also located within the base (Figure 3). The base employs over 10,000 military and civilian personnel and has about 5,000 on-base residents (military families). NSB-Bangor is essentially a self-contained suburban community.

The base has an existing Stormwater Pollution Prevention Plan (SWPPP) (Ecology and Environment, Inc., 1996) that was approved in 1996. This plan is in compliance with the 1972 Clean Water Act (CWA) and the 1987 Water Quality Act (WQA). These laws established a framework for regulating the discharge of municipal and industrial stormwater under the National Pollutant Discharge Elimination System (NPDES) permit program as administered by the US Environmental Protection Agency (EPA). The SWPPP identifies existing and potential sources of pollutants, primarily associated with industrial activities on the base, that may reasonably be expected to affect the quality of stormwater discharges; defines selected BMPs that are designed to minimize pollutant levels in NPS discharges; and establishes a time line for implementing the plan and monitoring the effectiveness of the recommended measures. The SWPPP addresses the requirements of the NPDES program for industrial (nonconstruction) and construction-related activities. As part of the SWPPP development, all industrial facilities on the base were inspected, potential contaminants were identified, and stormwater samples were collected. Nineteen illicit connections of nonstormwater discharges to the stormwater network were identified. These problems have been or are being corrected. Existing BMPs were also inspected and evaluated for effectiveness. As part of the SWPPP, a three-phase prioritized (three-year) plan to construct new mitigation facilities is currently under way. In addition, an inspection program for BMP facilities and a NSB-Bangor stormwater monitoring plan are also outlined in the SWPPP.

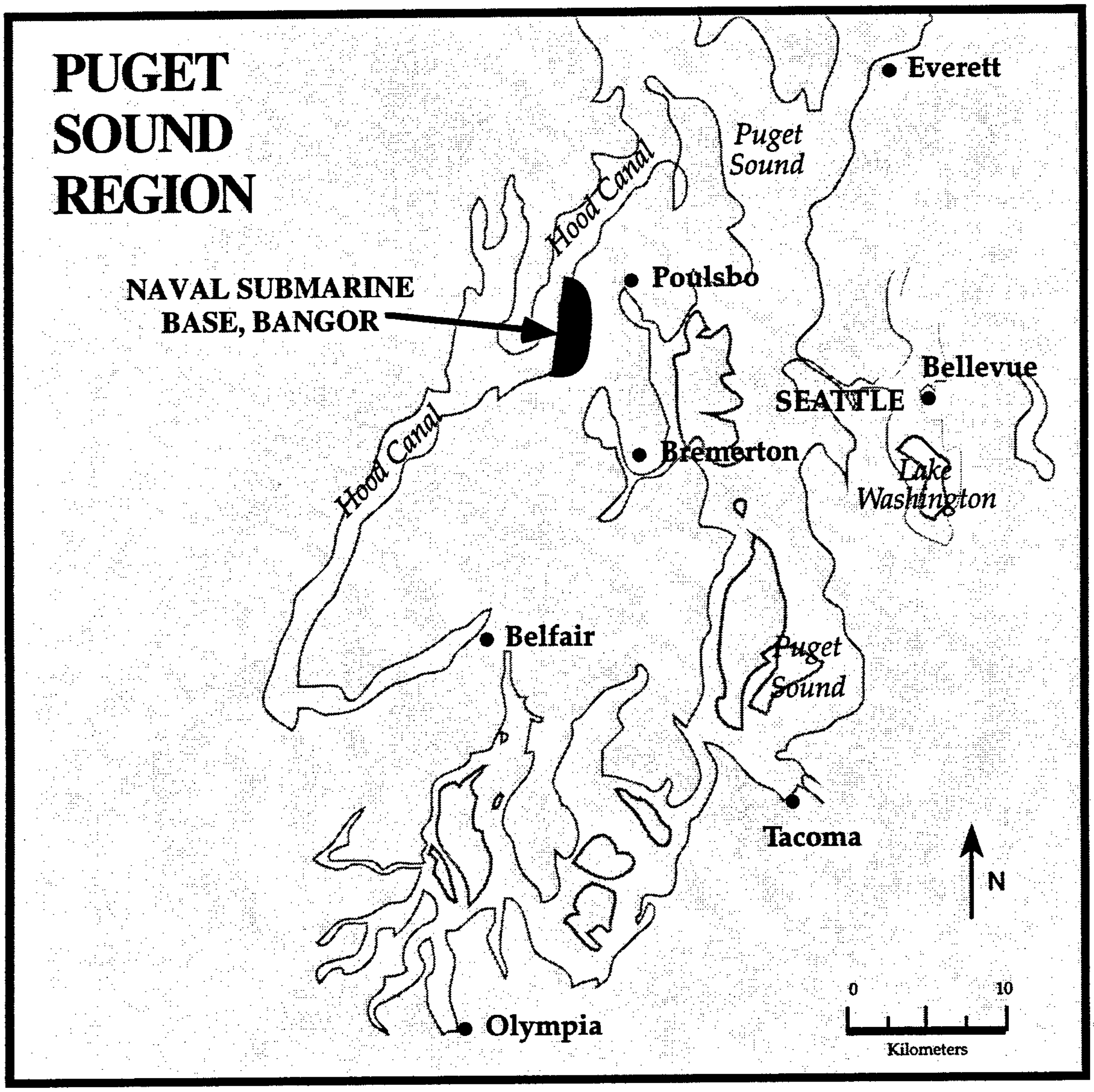


Figure 2. Site of the Naval Submarine Base, Bangor, Washington

US Navy stormwater regulations and policies are stipulated in the Department of the Navy Environmental and Natural Resources Program manual (OPNAVINST 5090.1B). These regulations state that *Navy facilities must comply with all requirements of the CWA and must meet all applicable federal, state, and local stormwater permit requirements*. The use of the best available technology for reducing pollution is also stipulated. The general Navy policy on stormwater management and NPS pollution control requires each command to ensure that all cognizant activities comply with the requirements of the permits under which the activity is covered. An EPA NPDES permit application was completed in 1993 for industrial activities at NSB-Bangor.

Because the base is located on the sensitive and relatively pristine waters of Hood Canal, hazardous waste reduction and cleanup have been a priority. The history of the base as a major weapon-storage facility has generated several hazardous waste sites. These sites are currently being or have been remediated. The base also has an active oil spill prevention and control plan, including an emergency response team for both hazardous materials and oil spills. The NSB-Bangor stormwater management program is administered by the NSB Public Works Department. Each command or facility on the base is responsible for compliance with stormwater and NPS pollution-control requirements.

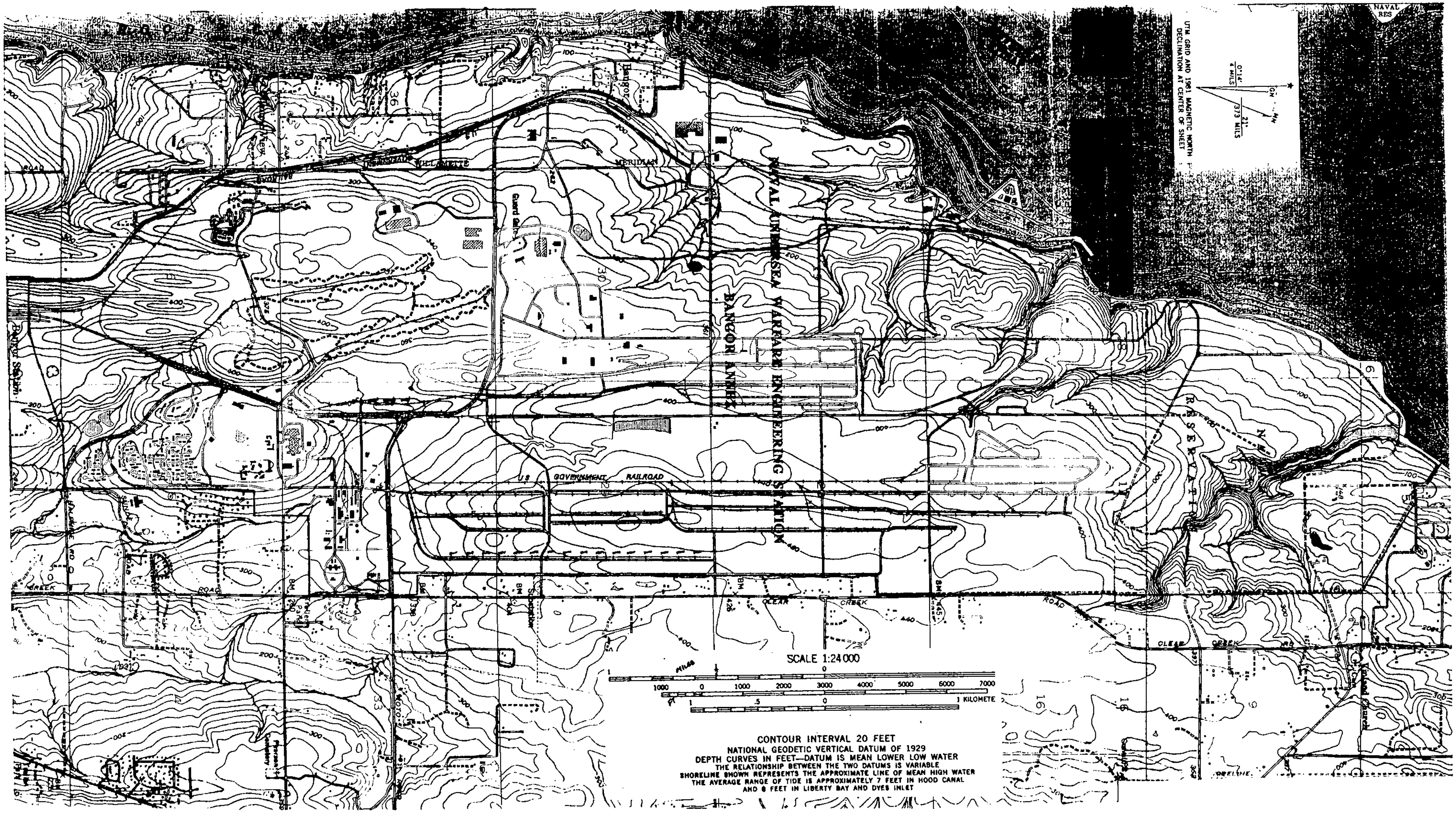


Figure 3. Map Naval Submarine Base, Bangor, site.

SITE DESCRIPTION

The Naval Submarine Base, Bangor, comprises 6,785 acres, over 50% of which are undeveloped, natural forested areas, and includes three small-stream watersheds (Figure 4). Stormwater treatment facilities include both natural conveyances (streams and wetlands) and constructed conveyances (swales, ditches, and culverts), as well as retention and detention facilities. Most stormwater runoff is infiltrated and/or treated by engineered facilities prior to entering the natural surface-drainage network. All stormwater is treated prior to leaving NSB-Bangor boundaries. Stormwater treatment ponds provide for sedimentation and limited removal of NPS pollutants. Each R/D facility includes an oil/water separator at the inlet of the pond. The main stormwater treatment ponds are

- Trident Lakes Retention Ponds (Clear Creek)
- Industrial Area Retention Pond (Clear Creek)
- Delta Pier Retention Pond (Hood Canal)
- Marginal/Service Pier Retention Pond (Hood Canal)
- Explosive Handling Wharf Retention Pond (Hood Canal)
- SWFPAC Retention Ponds (Devils Hole Creek).

Drainage basin boundaries were delineated based on SWPPP drainage maps, using topographic contours and schematic diagrams of stormwater drainage systems. The base contains 22 drainage basins (Table 1). Of these, only three are drained by streams that support native salmonids. These are Clear Creek, Devils Hole Creek, and Cattail Creek. The western portion of the base, including West Family Housing and SWFPAC, drains into the Hood Canal watershed, either directly or via Devils Hole Creek and Cattail Creek. Most of the eastern portion of the base drains into Clear Creek, which then flows into Puget Sound at Dyes Inlet in Silverdale.

The *Clear Creek* watershed is the largest drainage basin on the base. The headwaters of the north and south tributaries of Clear Creek are located within NSB-Bangor jurisdiction. Clear Creek supports runs of coho and chum salmon as well as resident cutthroat trout. Treated stormwater from NSB-Bangor feeds into Clear Creek. A relatively new stormwater-treatment pond services the Public Works complex (north tributary), the only industrial area within the Clear Creek basin. The Trident Lakes stormwater ponds service the south tributary of the creek, handling most of the runoff from East Family Housing and the base exchange complex (retail and recreational facilities).

Table 1. Naval Submarine Base, Bangor, subbasin summary.

Subbasin #	Drainage Area (acres)	Receiving Water	Subbasin Location/Description	Subbasin %TIA	Major Impervious Surface Areas
1	413	Clear Creek**	South Tributary (via Trident Lakes)	30	Roads/Parking Lots Recreation Complex Service Station/Auto Hobby Shop Base Car Wash East Family Housing
2	1500	Clear Creek**	North Tributary (via PW R/D Facility)	30	Roads/Parking Lots Public Works (PW) Industrial Area Retail Store (NEX) Complex Base Admin/Comm Station/CSG-9 NUWC Annex BEQ Complex
3	1142	Devils Hole Lake*	Devils Hole Creek	20	Roads/Parking Lots Trident Refit Facility Industrial Support Facilities Transportation Depot SWFPAC
4	505	Hood Canal	Hunter's Marsh	5	Roads/Structures
5	901	Cattail Lake*	Cattail Creek	5	Roads/Structures Off-Base Development (Vinland)
6	136	Hood Canal	Marginal Creek	5	Roads/Structures
7	16	Hood Canal	Service Pier	20	Roads/Structures
8	7	Hood Canal	Service Pier	10	Roads/Structures
9	4	Hood Canal	KB Docks	25	Roads/Structures
10	7	Hood Canal	Between Devils Hole & Delta	50	Roads/Structures
11	493	Hood Canal	Delta Pier Area	20	Roads/Structures
12	23	Hood Canal	Explosive Handling Wharf (EHW) (via R/D Facility)	80	Roads/Structures EHW Facility
13	11	Hood Canal	Marginal Wharf	20	Roads/Structures
14	1	Hood Canal	Marginal Wharf	100	Roads/Structures
15	1	Hood Canal	Marginal Wharf	100	Roads/Structures
16	1	Hood Canal	Marginal Wharf	80	Roads/Structures
17	2	Hood Canal	Marginal Wharf	10	Roads/Structures
18	1511	Hood Canal	Southwest Corner of NSB	30	Roads/Structures West Family Housing SWFPAC
19	542	Clear Creek**	East Central Portion of NSB North Tributary	15	Roads/Structures
20	15	Clear Creek**	Southeast Corner of NSB	20	Roads/Structures
			South Tributary		East Family Housing
21	73	Hood Canal	Between Marginal Wharf and EHW	10	Roads/Structures
22	338	Hood Canal	Northwest Corner of NSB	10	Roads/Structures
			Magnetic Silencing Facility (MSF)		MSF

Devils Hole Creek (Figure 4a) is the largest of the Hood Canal streams. The headwaters of this creek are almost entirely within the restricted boundaries of SWFPAC, which consists mainly of open (grass-covered) land, roads, and weapon-storage buildings. The creek also flows through the Trident Refit Facility industrial area before entering Devils Hole Lake. While the headwaters have been affected by development, the segment of the creek between TRF and Devils Hole Lake is relatively undisturbed. This man-made lake drains directly into Hood Canal via a fish ladder which affords access to the creek for anadromous salmonids.

The *Cattail Creek* watershed (Figure 4b) encompasses most of the sparsely developed northern portion of the base. This creek is an excellent example of a typical Hood Canal small-stream subbasin. The headwaters of the creek are located outside the boundaries of the base in a relatively low-gradient area which was probably once dominated by wetlands but is now undergoing residential development. For much of its length, the stream flows within a steep-walled ravine. Cattail Creek, along with Devils Hole Creek, can be classified as having a forced pool/riffle morphology. Large woody debris (LWD) provides the main structural component of these types of streams and is responsible for the in-stream habitat complexity that is critical to maintaining a natural salmonid community and a high level of ecological integrity. The creek drains into another artificial lake (Cattail Lake), which flows directly into Hood Canal via two level-control structures. This outlet has no fishway and therefore has effectively blocked all anadromous salmonid migration upstream. The lake is stocked for recreational fishing.

The *West Family Housing* area can be considered a separate subbasin. This catchment does not drain to any significant surface-water system (lake, wetland, or stream). Prior to construction of housing developments, this area was mainly second-growth coniferous forest (mainly firs and cedars). Natural drainage was through a network of swales and small (pocket) wetland areas. The design of housing areas did not incorporate any stormwater treatment or control facilities other than existing "natural" detention areas (swales and low-lying areas). This has resulted in some significant problems.

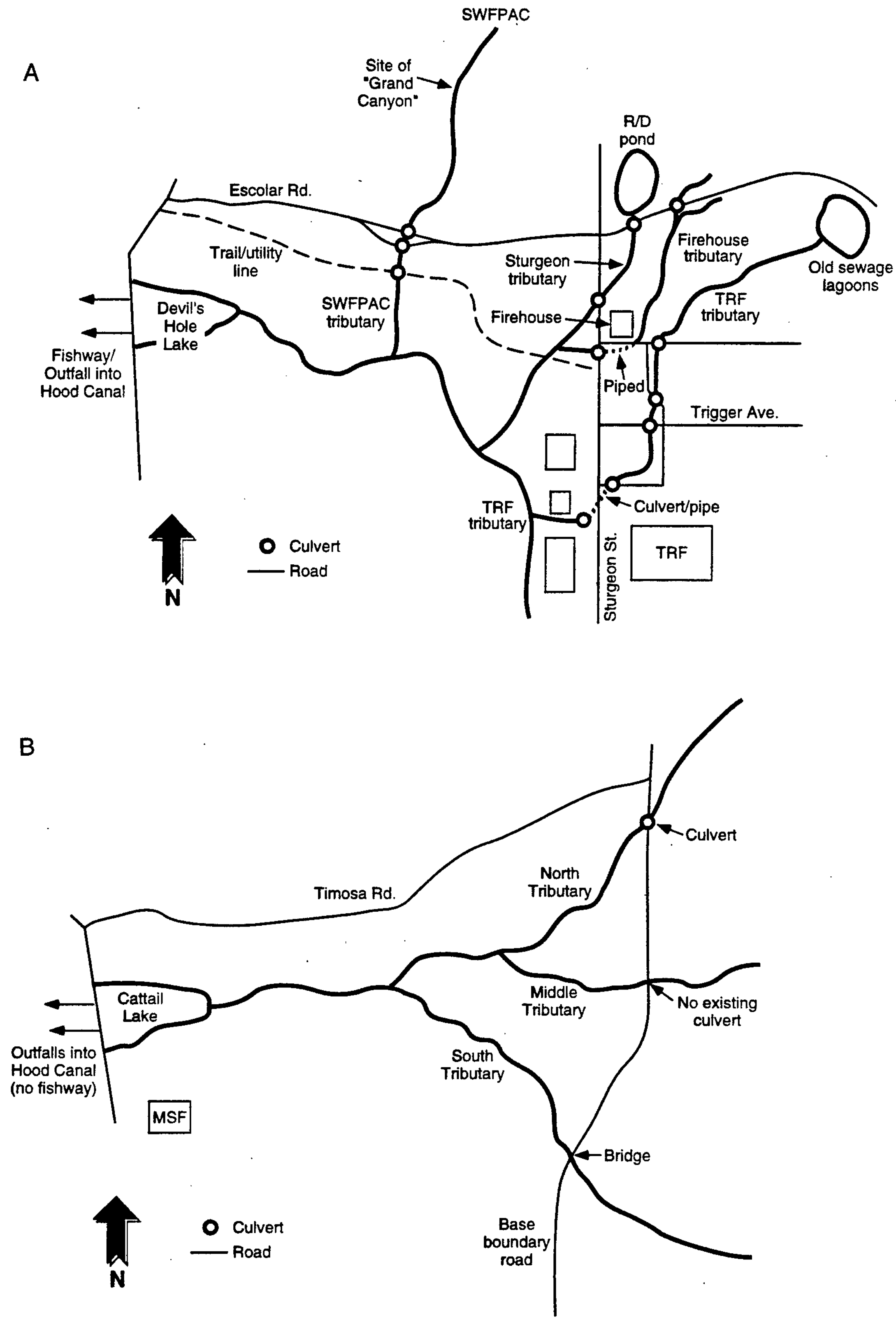


Figure 4. Map of NSB-Bangor subbasins. A. Devils Hole Creek. B. Cattail Creek. (The Clear Creek subbasin has been omited, as only its headwaters are on the base.)

WATERSHED APPROACH

Introduction

Water is a significant natural resource. The aquatic ecosystems that depend on adequate, high-quality water are important from both a socioeconomic and an ecological perspective. In the PNW, salmon and the stream ecosystems that support them are especially important to the regional economy, as cultural icons, and as symbols of the quality of life people associate with this part of the country.

The watershed, or catchment, is the basic unit of water resources management. A watershed encompasses the drainage area of each individual surface-water network (lake, stream, or river). Activities at any location in the watershed may have a negative impact on downstream resources. The watershed management approach has proven to be effective in minimizing the effects of development on sensitive aquatic resources (Schueler, 1995).

The quality of water resources depends on numerous physical, chemical, and biological variables. The sum of these physical, chemical, and biological factors is often referred to as ecological integrity. A natural level of ecological integrity is synonymous with a high level of stream quality. Healthy, self-sustaining salmon and trout populations require high stream quality. Stream quality (ecological integrity) includes the physiochemical quality of the water, the hydrologic regime in the watershed, the conditions of in-stream habitat, and the riparian infrastructure. In general, the degradation of stream quality is directly related to the level of human activity (development) within a watershed (Schueler, 1995; May, 1996). Because of its gradual, incremental nature and the delay between development activity and environmental impact, development is difficult to manage. In addition, watersheds often cross jurisdictional boundaries, which complicates the decision-making and management process. *Watershed management is most effective if it is resource driven and based on a sound scientific foundation.*

According to the US EPA (www.epa.gov/OWOW/watershed), the watershed approach is made up of these key components:

- *A focus on a critical resource(s)* such as salmonids, drinking water supply, recreation, or shellfish.
- *A geographic focus* based on the natural boundaries of the drainage system and surrounding landscape. These boundaries may cross state, local, or tribal jurisdictional boundaries.
- *Adaptive management* based on sound scientific data, tools, and techniques. This requires developing an intimate knowledge of the watershed, identifying and prioritizing problems, and devising action plans and solutions.
- Community-building, including inter- and intragovernment partnerships with citizen groups, the business community, and landowners. It is important to involve all stakeholders in the process of designing and implementing watershed action plans.

Resource Protection Strategy

An important goal of watershed management should be the protection of natural resources. As was stated earlier, in the PNW, the critical resource is most often the native salmonid community. This should be a main focus of any restoration or protection efforts involving surface waters. As Figure 1 indicates, the resource protection strategy involves an interdisciplinary, multifaceted approach to resource conservation. This approach includes the following key elements:

1. Watershed-based land-use planning
2. Reducing impervious surface area
3. Limiting erosion during construction activities
4. Treating stormwater runoff for both quantity and quality
5. Preserving high-quality stream ecosystems
6. Protecting sensitive areas
7. Establishing wide, forested riparian buffers
8. Monitoring, education, and public outreach
9. Establishing a stream rehabilitation program.

The recommendations presented in this report are based on data gathered during 1997 and are guided by the principles of the stream protection strategy outlined above.

STUDY METHODS

Puget Sound Lowland Stream Study

During the period 1993–1996, a group of 22 lowland streams was selected as a subset of all Puget Sound lowland (PSL) streams to examine the effects of urbanization on stream ecosystem integrity, water quality, and salmonid habitat. The streams were chosen to represent a range of low to high land-use development levels. Land-use patterns characteristic of urbanized and/or urbanizing basins included residential, commercial, and industrial categories. Watersheds where the primary land use was agriculturel or resource extraction (timber harvesting or mining) were excluded. An important criterion for selection was that streams currently support or have supported at least one species of salmonid; all have or have had coho populations. Stream selection was also influenced by geographic and logistical considerations. Streams were selected to provide a gradient of urbanization levels in order to demonstrate a link between urbanization and stream quality.

The PSL ecoregion encompasses the entire Puget Sound basin from sea level up to the Cascade and Olympic mountains. Ecoregions are characterized by a similar geologic history, soils, land form, vegetative succession, and land-use patterns (Omernik and Gallant, 1986). Streams of the PSL ecoregion are fed primarily by precipitation, are low-gradient and meandering, and are dominated by a pool/riffle morphology. Most soils in the PSL are glacial in origin and are strongly influenced by the dominant coniferous forest vegetation (Douglas Fir, Western Hemlock, Western Red Cedar). Glacial activity in the recent geologic past is responsible for the current geomorphologic characteristics common to stream systems of the region (Detenbeck et al., 1992).

Precipitation patterns within the region can vary considerably, but the overall characteristics are similar. The bulk of the precipitation occurs between October and March, with a dry summer period from July through September. The historic precipitation pattern for the PSL is 40 cm in the fall, 35 cm in the winter, 15 cm in the spring, and less than 10 cm during the summer (100 cm total). Snowfall is infrequent and rain on snow is rare.

Stream Classification

Detecting and predicting the effects of land-use activity on stream habitat and aquatic biota is complicated because the responses to disturbance can occur over a variety of spatial and temporal scales (Frissell et al., 1986). Natural processes also interact with human-induced disturbances. Physical habitat features also vary from site to site and may, therefore, vary in sensitivity to disturbance. Nevertheless, the long-term geologic and geomorphic structure of the drainage basin can be viewed as a template which structures the complex response of the stream system (Frissell et al., 1986).

The natural geomorphic characteristics of each stream were determined before comparing the level of urbanization and degree of degradation among streams. The reasoning was that if the morphological characteristics of each stream were known, then inferences could be drawn about the streams' natural disturbance regimes and their expected response to urban impacts. Without a systematic classification scheme, patterns of stream response to urban disturbance would be confounded or masked by natural variation. This study was designed along the hierarchical framework of stream system classification outlined by Frissell et al. (1986). Streams were characterized by their watersheds and landscape-level characteristics. This scheme emphasizes a habitat-centered view of the stream's relationship to its watershed over a range of scales in space and time. The stream network is hierarchically organized into levels: stream system, segment, reach, habitat feature (pool/riffle), and microhabitat. Stream responses were assessed at various levels within this framework.

The Rosgen classification scheme, which stratifies stream segments based on similar geomorphic characteristics, was chosen for comparison of stream segments (Rosgen, 1994). Ensuring that streams are of a similar type reduces the variation that might appear to be natural but may actually be due to comparing inherently different systems. Morphologic characteristics of the stream channel are determined by physical processes, primarily those of a fluvial nature. The morphologic characteristics of the channel are influenced by several variables (Leopold et al., 1964). These include channel width, channel depth, water velocity, discharge (volumetric flow), gradient, floodplain features, streambed roughness, channel structure, longitudinal profile, sediment load, and sediment/substrata size. A change in any one of these variables initiates a series of adjustments in the other variables until the channel reaches a new equilibrium. These physical variables are used in the Rosgen classification system as "delineative criteria" (Rosgen, 1994) and represent the dominant features of the stream channel. The Rosgen scheme is hierarchical, beginning with the stream segment as either a single or multiple channel. The segment is further classified by the entrenchment ratio, defined as the ratio between the flood-prone width (FPW) and the bank-full width (BFW), and then by the bank-full-width/bank-full depth (BFW/BFD) ratio. Finally, sinuosity and slope are determined. An additional level of classification based on the size of the dominant substrata may also be used. Based on segment classification, the Rosgen system also provides interpretive information on sensitivity to disturbance, recovery potential, sediment dynamics, level of influence of riparian vegetation, streambed stability, and stream-bank erosion potential. This interpretive information can be used in designing a watershed management plan, in a cumulative effects analysis, and for restoration/enhancement guidance. A main criticism of the Rosgen method, as with other classification schemes, is that LWD is omitted, which reflects the nonforested environment for which it was designed. However, the classification tool is still useful.

Watershed Characterization

Watershed characterization is the description of the current natural and human-related attributes of the basin and includes

- Dominant natural and human features of the watershed that affect ecosystem function and biological integrity.
- Cataloged and/or mapped watershed attributes such as geologic, soil, and topographic characteristics.

- Key land-use features and land-cover patterns, including roads, forested areas, and development levels, usually on a map.
- Municipal jurisdictions and regulatory responsibilities within each watershed.
- Current and historic salmonid utilization for each stream system.
- A list of beneficial uses common to the watershed and their relative importance.
- Unique or critical resource issues and problems.
- Water-resource management programs that currently exist.

Watershed-level information was derived primarily from the most current USGS topographic maps and aerial photographs. Basin plans, maps, and data from cooperating agencies were also utilized. Drainage basin area and watershed boundaries were determined according to drainage patterns and contour lines, in accordance with standard methods (Dunne and Leopold, 1978). A standard "English-grid" was also used to determine sub-basin areas if no other data were available. Stream lengths, valley slopes, and stream gradients were derived from topographic maps using a map wheel and a slope-indicator template. Stream lengths were measured as "logical" extensions of blue lines on topographic maps, in accordance with standard methods (Dunne and Leopold, 1978). This technique was originally proven to be statistically accurate for field conditions by Morisawa (1957) and is the preferred method. This method involves inserting streams into the drainage network wherever there are "V-shaped" contours and extending channels just beyond the last contour.

Drainage density (DD) was calculated based on natural conditions, using the stream channel length indicated by the undeveloped basin topography, and then again based on the current developed conditions. For the developed or “artificial” condition, roads that provided direct drainage paths for runoff into the stream system and storm sewer outfalls were included in the drainage network. With increased urbanization, there is usually a reduction in the natural drainage system, but a significant increase in overall drainage density (Graf, 1977). Land-use data were compiled from a variety of sources in an attempt to develop the most accurate and up-to-date picture of the current conditions in each basin. Land-use maps, computerized data, data from satellite imagery, and aerial photographs were used to compile the data required to calculate the various measures of urbanization.

Riparian Zone Assessment

Riparian zone integrity, based on the quantity and quality of riparian forest areas, was assessed primarily from aerial photographs. Field surveys were utilized to update the aerial photographs where photographic coverage was not up to date or adequate. The longitudinal integrity of the riparian corridor was determined based on the number of significant breaks in the riparian zone/kilometer, including breaks due to roads, trails, utility right-of-ways, and storm sewer outfalls, regardless of the type or width of the discontinuity.

The width of the riparian buffer zone was defined as the lateral distance outward from each stream bank and was calculated as the mean width on the right and left banks for each reach. This value was calculated by dividing the total area of riparian forest for each reach by twice the length of the stream channel (Barton et al., 1985; Johnson and Ryba, 1992; Castelle et al., 1994). A variety of recommended buffer widths is found in the literature, based on the functional attribute being supported. The length of the riparian buffer zone was determined for each of five categories and converted to a percentage of the total length of the segment. The five buffer width categories used in this study were

- <10 m
- 10–30 m
- 30–50 m
- 50–100 m
- >100 m.

The quality of the riparian buffer was judged based on the dominant forest composition (coniferous, mixed, or deciduous) and successional stage (old-growth, mature, young, shrub, or grass). The potential for acquiring (recruiting) new LWD was scored based both on current in-stream and riparian conditions and on the ability to meet future LWD requirements. The overall riparian quality for each segment was scored as either optimal (4), suboptimal (3), marginal (2), or poor (1). The observed riparian characteristics were also noted. Again, all riparian measurements and conditions were checked in the field to ensure that the aerial photograph analysis was current and accurate.

Reference Streams

Assessing the physical, chemical, and/or biological effects of urbanization on streams and watersheds requires either a control (reference) site or at least an unbiased estimate of the "best case" conditions attainable. These "regional reference sites" should have the same land-surface form, underlying geology, soils, vegetation patterns, and climate as the streams and subbasins under study (Hughes et al., 1986) and represent the optimal conditions against which urbanized streams are compared. Such reference streams in undeveloped or low-impact watersheds can also provide goals for preservation, enhancement, and restoration.

For the NSB-Bangor study, relatively undisturbed streams and watersheds within the PSL were selected as reference sites. Because of the history of timber harvest and regional development, these reference sites are not really pristine, but it was assumed that they were as near to naturally functioning and ecologically intact streams as exist and that they would provide the long-term stability and diverse habitat necessary to support a full range of salmonid species (Peterson et al., 1992). The biota, chemical water quality, and physical habitat characteristics of the regional reference sites serve as benchmarks for the disturbed streams and watersheds.

Imperviousness

The most common measure of urbanization level is the percentage of watershed area that is covered by impervious surfaces. Impervious surface is defined as any surface that prevents or inhibits the natural infiltration process. Examples include roads, parking lots, and rooftops. Vegetated areas such as lawns, golf courses, and parks can also be considered relatively impervious, owing to the removal and compaction of surface soils during development. Imperviousness is used as a measure because of the underlying relationship between the amount of impervious surface and the magnitude of runoff: Except at very low rainfall levels, where soils and slope factors tend to dominate, and where excessive runoff is not a major problem (Schueler, 1994), there is a direct increase in the runoff coefficient with increasing imperviousness. The runoff coefficient represents the fraction of rainfall volume that is actually converted to stormwater runoff. The population density of an area is also highly correlated with the percentage of impervious area.

The rationale for using imperviousness as an indicator of development is widely accepted. Imperviousness is integrative in nature and can represent an index of cumulative effects on aquatic resources irrespective of specific land-use factors or complex NPS pollution problems (Arnold and Gibbons, 1996). Although impervious surfaces do not generate pollution themselves, they accumulate pollutants, convey stormwater, and inhibit infiltration of runoff. They are thus a major contributor to the change in a basin's hydrologic regime and are a significant component of urban land uses that generate pollutants (Arnold and Gibbons, 1996).

The most common measure of imperviousness is the percentage of total impervious area (%TIA) and is based on assigning a regionally accepted, specific percent imperviousness to the various categories of land use found within each basin (Alley and Veenhuis, 1983; Prych and Ebbert, 1986; Taylor, 1993; Schueler, 1994; Olthof, 1994). The extent of imperviousness in each basin was determined by first measuring the areas covered by each type of land use. The total area covered by impervious surface in each land-use category was estimated based on hydrologic studies of typical development patterns for these land-use types. The land-use %TIA values were multiplied by the surface area devoted to each land use to obtain a final %TIA for each basin.

While the use of %TIA is a generally accepted index of urbanization, it is partly subjective. Dividing each basin into polygons of land use, calculating their areas, and assigning a land-use category is a complex task requiring detailed land-use maps and/or aerial photographs. Land-use categories must then be assigned a %TIA value. This is typically based on representative levels of TIA for that particular type of land use and the corresponding runoff coefficients. Commonly accepted values for land use impervious were used in this study.

Typically, the largest contributors to impervious surface in urbanizing basins are rooftops and road surfaces, including roads, parking lots, and driveways. Traditional zoning regulations emphasize the rooftop component of imperviousness, usually at the expense of roads. Housing density is usually regulated but not road density. The rooftop impervious component is emphasized in the %TIA calculation. However, the road-surface component often substantially exceeds the rooftop component. In a typical area of mixed land use (residential and commercial), 60–70% of the impervious surface may be composed of roads and other paved areas (City of Olympia, 1994). This is a direct result of the rise in per-capita automobile ownership and increased usage of the car as the preferred mode of transportation.

The importance of the road component of imperviousness is indicated by the wide range of impervious values for the same zoning category, depending on the layout of the streets (Schueler, 1994). Therefore, road density is also proposed as an alternative or a complement to %TIA as a measure of urbanization. Eaglin and Hubert (1993) found road density and road crossings to be strongly correlated with in-stream habitat degradation and fish abundance in a forested basin of the western US. Transportation-related imperviousness often exerted a greater hydrological impact on streams than rooftop runoff (Bannerman et al., 1993; Schueler, 1994; Arnold and Gibbons, 1996). Roads and parking-lots are usually directly connected to the storm drainage system and the nearest stream, whereas rooftop runoff tends to drain via more diffuse routes.

Road density (kilometers of road per square kilometer of basin) was measured using the most current road map, aerial photographs, or computer database. The "baseline" road was considered to be a typical residential street. All roads were treated equally with the exception of multilane arterials or highways, which were counted as a multiple of the baseline road. Variation in road surface materials (i.e., concrete, asphalt, gravel, or dirt) was not considered. Road/stream crossings were identified from aerial photographs and field reconnaissance.

Stream Segment Delineation

Study streams were examined on two levels. Watershed-level sampling and surveys primarily included hydrologic variables and physiochemical water quality. Each stream system was also subdivided into "segments" for assessing physical habitat and morphological characteristics of the channel. A combination of aerial photographs, topographic maps, land-use maps, and field surveys was used to delineate stream segments. As was discussed earlier, all stream segments were classified based on a standard set of criteria (Rosgen, 1994) and were surveyed in the field to verify current conditions. Morphological characteristics were used as the primary criteria for segment delineation. Segments were then subdivided based on dominant subbasin land use.

Because of access limitations and logistical considerations, the segments surveyed were not always continuous. In most cases only limited portions of a stream segment (called the survey reach) were surveyed. Survey reaches varied from several hundred meters to several kilometers long. Because of the morphologically based determination of segment length, as well as field constraints, a statistically valid minimum segment length (sample size) was not determined prior to data collection. The variance for each segment was therefore estimated in order to calculate (with 90% confidence) a statistically adequate, minimum survey reach (Zar, 1984) for each major parameter of the physical habitat (e.g., LWD and pools). If a surveyed reach was less than the statistically required minimum length, then that reach was not used in later analyses.

In-Stream Habitat Assessment

Field surveys were conducted to compile a continuous record of features within each reach, including stream-bank conditions, LWD, and channel morphology. Detailed characteristics of the physical habitat, including pools, riffles, and streambed substrata, were also measured. The current conditions of each stream segment were evaluated with the objective of relating the variability in stream conditions within the PSL region to the degree of development upstream and in adjacent watersheds. Details and background information on field sampling/survey procedures are contained in the PSL Habitat Assessment Protocols (May, 1996). The habitat characteristics determined are all considered potential indices of urbanization and relate either directly or indirectly to salmonid habitat. Effective indices should be objective, consistent, and relatively sensitive to human disturbance. The characteristics determined include

1. Riparian canopy closure (% shaded)
2. Riparian buffer quantity and quality
3. Stream-bank cover and erosional conditions
4. Riparian land use and human impact level
5. Stream-channel gradient, sinuosity, and confinement
6. Bank-full dimensions (BFW and BFD)
7. Flood-prone width (FPW)
8. Streambed-substrata size distribution
9. Streambed-substrata embeddedness
10. Spawning-habitat quantity and quality
11. Rearing-habitat quantity and quality
12. Large-woody-debris (LWD) quantity and quality.

Riparian canopy cover was measured at regular intervals in each stream segment using a standard spherical densiometer (Lemmon, 1957). This device measures angular canopy density and cover, both widely accepted measures of shading related to light availability and water temperature. Riparian-zone conditions—such as width, dominant species, and successional stage—and noticeable human disturbance directly adjacent to the study reach were also recorded. Stream-bank conditions were observed to quantify stream-bank erosion, using a combined stream-bank stability index. Stream segments where >75% of the bank was classified as stable were scored 4. Segments where 50–75% of the bank was stable were scored as 3, 25–50% as 2, and <25% as 1. Artificial protection (riprap) was considered a sign of bank instability and was scored 1.

Stream-channel morphologic characteristics, including bank-full dimensions, stream gradient, and floodplain character, were recorded at regular intervals along the stream lengths. Stream-channel gradient was measured at 100-m intervals on each reach surveyed using a standard clinometer, and values were checked against topographic maps. Stream-channel confinement, whether due to natural geomorphic features or human intervention, was classified as unconfined, moderate, or confined. Channel sinuosity was classified as high, moderate, or low through the use of standard compass bearing and stream-length measurements. The bank-full width and depth (BFW and BFD) of the active channel were measured every 50 m and averaged for each sample reach. Flood-prone width (FPW) was also measured and averaged for each reach (Dunne and Leopold, 1978).

Classification of the streambed size distribution was based on a sampling method originated by Wolman (1954) which is quick, is statistically reliable, and provides information on the substrata particle size distribution. The method was subsequently modified for fish habitat assessment by Kondolf and Li (1992) and then by the US Forest Service (Bevenger and King, 1995) to characterize stream reaches containing a continuum of habitat features (pools, riffles, and glides); this was done to detect the shift toward fine sediment in reaches affected by human activity compared to reaches in reference streams. Samples from several reference reaches are recommended so that variability in the reference condition can be well defined. However, a limited number of undeveloped reference streams were available in the Puget Sound region. Substrata particle embeddedness was measured as a simple average percentage for each stream reach.

The stream-habitat surveys were patterned after standard procedures used to assess physical habitat in forested streams (Bisson et al., 1987; Lisle, 1987; Hankin and Reeves, 1988; Robison and Beschta, 1990; Peterson et al., 1992; Ralph et al., 1994; TFW, 1994). Three main features were recorded: pools (rearing habitat), riffles (spawning habitat), and LWD. Habitat was assessed during the low-flow period between June and September. Each segment varied in length based on various practical and logistical constraints, but at least 25% of each stream segment was sampled. Very long (>2 km) segments were usually subdivided and sampled at multiple locations to be representative.

The types of habitat and their surface areas were also recorded (Bisson et al., 1982); types were categorized as scour, dam or plunge pools, etc., and high-gradient or low-gradient riffles. Residual pool depths (RPD) were determined according to the method of Lisle (1987). RPD is defined as the difference between maximum and tailout depths, which estimates pool depth under no-flow conditions. The amount (%) of cover over each pool was visually estimated. The following data were recorded from these observations:

1. Number of pools/kilometer
2. Pool spacing
3. Pool area/kilometer and average pool area
4. Mean residual pool depth
5. Percentage of pool area
6. Percentage of riffle area.

The number, size, in-channel position, and quality of LWD within the active channel were also determined. Any organic debris >0.1 m in diameter and >1 m in length was recorded. Each individual piece of LWD was measured and its volume calculated, but pieces in debris jams were often estimated. Artificial log weirs and deflectors comprised a portion of LWD in many urban streams and were identified as such. LWD was classified according to type (log or root wad), species (coniferous, deciduous, or man-made), decay condition, stability, and location in the active channel. A LWD quality rating was determined. Values were obtained for each of the following LWD characteristics:

1. Number of LWD pieces per kilometer
2. LWD frequency
3. LWD volume per kilometer
4. Mean LWD volume index
5. Percentage of pools formed by LWD
6. LWD quality (position, species, and decomposition).

Although quantitative data are relied on most heavily, most agencies responsible for stream assessment in the PNW use some form of qualitative assessment. A qualitative habitat assessment was designed using a combination of indicators (metrics) from existing state and federal survey forms (Plafkin et al., 1989; Rankin, 1989; Plotnikoff, 1993). For this survey, each habitat parameter was graded as optimal, suboptimal, marginal, or poor. A score of 4, 3, 2, or 1, respectively, was subjectively assigned for each indicator. Scores for all 15 metrics were summed to obtain a total qualitative habitat index (QHI). The maximum possible score was 60, and the minimum was 15. In order to minimize sampling bias, all QHI surveys were completed by the same individual.

FINDINGS

Cattail Creek Subbasin

Cattail Creek is the least developed subbasin within the base. Its stream system is relatively unaffected by human activities and has high overall ecological integrity. The stream has the potential to support salmonid populations, both resident and anadromous. Cattail Lake, the wetland area around its inlet, and the mainstem of the stream itself have diverse and complex in-stream habitat. There is adequate spawning and rearing habitat within the stream system. The quality of the riparian zone is generally excellent. The major salmonid-related problem for this watershed is the lack of a fishway (fish ladder) at the outlet of Cattail Lake on Hood Canal. Any historical runs of coho or chum salmon have long since been lost owing to this migration barrier.

This watershed is distinguished in that its headwaters are predominantly located outside the jurisdiction of NSB-Bangor. The headwaters of the north and south tributaries are entirely outside the base. The smaller, middle tributary also begins just outside the base boundary. This results in a difficult watershed management issue. The headwaters of this creek are located in an area of northern Kitsap County that is undergoing a significant amount of residential development. The headwaters of the north, south, and middle tributaries are located in the Vinland area, which is predominantly zoned as low-density residential. To minimize impact on the downstream portion of Cattail Creek, the headwaters should be protected, and any development in these areas should include stormwater mitigation measures. Headwater wetlands and the stream's riparian corridor should be preserved. This will require NSB-Bangor to work closely with Kitsap County to minimize the impacts of future upland development on the stream channel. This is a relatively confined, moderate-gradient stream with the potential for erosion of the stream bank and incision of the streambed if flows increase in magnitude and frequency owing to upstream development.

The mainstem of Cattail Creek is generally in a natural condition. There are several mass-wasting (landslide) sites along the side slopes of this creek, but this is typical of the highly confined stream channels that drain into Hood Canal. However, it should be noted that these types of stream channels can be highly susceptible to development pressure along the upland areas bordering on the incised valleys. Wide riparian buffers are required to reduce the chance of excessive mass-wasting due to runoff from developed areas. The recent washout of the bridge on the south tributary is an example of this problem. Road surface runoff from heavy rains overwhelmed the existing stormwater-conveyance system, causing a significant mass-wasting event which undermined the bridge-support structure. This resulted in the deposition of large amounts of sediment into the stream channel in addition to loss of the bridge.

There is adequate in-stream structure (LWD), and salmonid habitat is generally of high quality. LWD recruitment potential is generally good throughout the mainstem segment. The riparian corridor is predominantly mature coniferous forest. The lowest reach of the mainstem, prior to flowing into Cattail Lake, is composed of a high-quality wetland area that would provide excellent coho rearing habitat. The middle and upper reaches of the mainstem have excellent spawning habitat and adequate rearing habitat.

The north, middle, and south tributaries are less confined than the mainstem but generally have a higher gradient (2–4%). There is adequate in-stream structure (LWD), and the quantity and quality of salmonid habitat are for the most part good. All three tributaries pass under the NSB-Bangor boundary road. These locations are the only stream crossings that exist within the watershed. This is on one hand excellent, but it also presents a problem. The culvert under the north tributary road is perched and therefore is a barrier to fish passage. Little usable habitat exists upstream of the base on this tributary owing to development in the Vinland area, but there is some potential. The current culvert is undersized based on present and future development upstream. There is no culvert under the NSB-Bangor boundary road on the middle tributary. While this tributary is currently neither a salmonid passage nor a flow problem owing to the ephemeral nature of the stream, future development upstream has the potential to wash out the boundary road during periods of high runoff. New, larger-diameter culverts are recommended for both the north and middle tributaries to alleviate these potential problems.

As was previously mentioned, the south tributary has already experienced high storm flows that resulted in a near washout of the existing bridge during the winter of 1996–1997. The configuration of the boundary road and the routing of road runoff are at least partially responsible for the severe mass-wasting that occurred along this section of the channel. The stream channel must be rehabilitated (LWD installed) and the valley slopes revegetated. In addition, the runoff from the boundary road should be routed through a stormwater-treatment facility and not allowed to run directly into the stream. The upstream segment of the south tributary has the most potential for salmonid utilization in the Cattail Creek headwaters.

Devils Hole Creek Subbasin

Devils Hole Creek drains the west-central portion of NSB-Bangor. The headwaters of the creek include the western section of SWFPAC and the Escolar Road corridor. The basin contains several industrial areas, the Trident Refit Facility (TRF) being the most notable. Several roads and parking lots are also situated in the upper and middle subbasins. The lower portion of the creek is relatively unimpacted until it enters Devils Hole Lake prior to draining into Hood Canal. Devils Hole Lake is a man-made impoundment with many characteristics similar to Cattail Lake. The wetland around the stream inlet is comparable in size and quality. In contrast to Cattail Lake, a fish ladder has been installed at the lake outlet to allow migration of anadromous fish. Coho and chum salmon, as well as cutthroat trout, currently utilize the stream system. The entire stream basin is located within NSB-Bangor, making watershed management relatively easy.

Devils Hole Lake, the wetland area around its inlet, and the mainstem of the stream itself have a diverse and complex in-stream salmonid habitat. There is adequate spawning and rearing habitat within the stream system. The quality of the riparian zone is generally excellent. Devils Hole Creek is a relatively confined, moderate-gradient stream with the potential for stream-bank erosion and streambed incision if flows increase in magnitude and frequency owing to upstream development. The lower mainstem is in a natural condition. There are several mass-wasting sites along the side slopes of this creek, but this is typical of the highly confined stream channels that drain to Hood Canal. As with Cattail Creek, it should be noted that these types of stream channels are highly susceptible to development pressure along the upland areas bordering on the incised valleys. Wide riparian buffers are necessary to reduce the chance for excessive mass-wasting due to runoff from developed areas.

The mainstem has adequate in-stream structure (LWD), and salmonid habitat is generally of high quality. LWD recruitment potential is generally good throughout this segment. The riparian corridor is predominantly mature coniferous forest. The lowest reach of the mainstem, prior to flowing into Devils Hole Lake, is composed of a high-quality wetland that provides excellent coho rearing habitat. The middle and upper reaches of the mainstem have excellent spawning habitat and adequate rearing habitat. There appears to be more fine sediment than would be expected in a completely natural stream. This may be due to human activities upstream.

The first major tributary of the creek enters from the north near the head of the wetland area. The headwaters of this tributary include a portion of SWFPAC that consists of open fields, roads, and structures. This is a relatively impervious area. The runoff from this area is collected and piped into a large swale that is lined with quarry rock. The runoff then flows through a culvert into a large infiltration basin. From there, the stormwater is directed into a forested area at the head of the stream channel. The tributary channel itself originates in a steep, severely incised ravine (the so-called "Grand Canyon") and flows into a low-gradient wetland area. This upper section of the tributary is strongly affected by development (SWFPAC) and degraded in quality.

The stormwater-control facility located just outside the SWFPAC boundary has not been maintained. The infiltration basin is overgrown with alders and brush. The outlet-control structure is improperly located, and stormwater runs straight through the basin without much treatment. The inlet structure is adequate, although additional quarry rock would provide a better dissipation of flow energy. To improve the overall performance of this facility, the following improvements are recommended:

1. Clear trees and brush from within the basin.
2. Place two or three check dams within the basin to absorb the flow of incoming stormwater and sequentially detain runoff in the facility.
3. Replace the outlet culvert with a level-control structure.
4. Channel the outlet through a hardened swale.
5. As an optional enhancement, construct a treatment wetland just below the current facility.

Runoff from the facility currently follows the natural topography through a forested area. A "knick point" has developed where the flow exits this forested area into a clearing where the gradient also steepens significantly. At this point the stream has incised a deep channel (the Grand Canyon) into the exposed till layer. Construction debris has been dumped into this incision in an attempt to control the erosion. The long-term solution to this problem will require implementing the above recommendations. In addition, the incised channel must be regraded, and a series of check dams should be installed. These check dams can be made from trees that are felled during the grading process (quarry rock will also be required). Because this segment of the creek is not accessible to salmonids, providing fish passage is not an issue. The area will also need to be revegetated with native trees (conifers) and ground cover when the project is complete.

Downstream of this section there is a natural riparian wetland where the stream channel is diffuse and lower in gradient. The SWFPAC tributary continues through a mature coniferous riparian forest and then through two culverts, one under Escolar Road and one under a utility road. The culvert under the utility road is perched above the stream and a barrier to upstream fish passage owing to excessive erosion of the streambed on the outlet side. The Escolar Road culvert is almost 2 m above the streambed. Both culverts are also undersized for current and future storm-flow conditions. The utility road culvert and the Escolar Road culvert should be replaced with larger, arched culverts to allow fish migration upstream and to accommodate larger flows.

The SWFPAC tributary then flows through another culvert under a combination utility access road and jogging trail. This culvert is also perched, forming a fish passage barrier, and is undersized for existing storm-flow conditions. On the upstream side of the utility-line crossing, a runoff channel enters from the east. Surface erosion and incision is evident here. There are also indications that excessive nutrients are entering the stream at this point. Consideration should be given to constructing a stormwater-treatment facility at this location to treat the runoff before it enters the stream. Downstream of this crossing, the SWFPAC tributary flows through a naturally forested, fairly deep ravine before joining with the mainstem of Devils Hole Creek. The channel is quite steep and has the potential for incision and stream-bank erosion.

The mainstem of Devils Hole Creek splits into two main tributaries in a low-gradient area behind the Sub-Mart and SWSMS complex (Buildings 7001/7002/7003). One tributary runs through the TRF complex; the other runs past the TRF firehouse in two smaller branches. The headwaters for both these tributaries include a good portion of SWFPAC to the east of Escolar Road. Both tributaries have R/D ponds in their uppermost reaches. Both flow through areas of second-growth, mixed forest and riparian wetlands. Both have good spawning and rearing habitat for coho salmon and cutthroat trout. The lowermost portions (downstream of Sturgeon Street) are in excellent condition, with high-quality, highly complex in-stream salmonid habitat. The middle portions (upstream of Sturgeon Street) have been significantly degraded by human activity in and around the TRF industrial complex. The upper portions are generally in good condition.

The west branch of the firehouse tributary has its headwaters within SWFPAC and drains into a two-cell stormwater-teatment facility (constructed wetland) on the upstream side of Escolar Road. The overflow from this pond goes through a culvert under Escolar Road and into the firehouse tributary. Road runoff from Sturgeon Street joins the west branch which flows through a forested section into the firehouse pond (which also serves as a children's fishing pond) and then under Sturgeon Street, where it joins the main firehouse tributary. The Sturgeon Street branch has generally fair in-stream quality and serves mainly as a stormwater-conveyance channel. Considering that this is primarily a runoff-fed tributary, stormwater quantity control and quality treatment should be a priority, and salmonid utilization should *not* be encouraged nor managed for.

The east (Sturgeon Street) branch of the firehouse tributary originates in the area around Escolar Road and is fed by both groundwater and surface (road) runoff. This subbasin is mainly forested (mixed mature) and is in generally good condition. The upper segment of this branch has pockets of good spawning and rearing habitat, as well as adequate in-stream structure and complexity (LWD). The section of the branch around the fire house is moderately affected by development pressure. This area was cleared within the past 5–10 years and has grown back with predominantly brush and alders. The riparian corridor near the firehouse is in need of enhancement. As a result of the loss of riparian forest and increased storm flows, there is a lack of in-stream LWD, and stream-bank erosion is common over the entire reach. In-stream LWD installation and bank stabilization is recommended.

The long culvert under Sturgeon Street is also undersized for current and future flow conditions. This culvert should be replaced with an arched culvert to facilitate fish passage as well as accommodate storm flows. The culvert's outlet on the west side of Sturgeon Street is currently buried under a layer of sediment deposited during last year's heavy storms. This makes the culvert totally impassable for migrating salmonids. This should be corrected as soon as possible. This excess sediment should be removed immediately to facilitate spawner passage and winter storm flows. The riparian corridor downstream of the Sturgeon Street crossing is also in need of enhancement.

The TRF tributary has its headwaters in SWFPAC, along Escolar Road, and in two former sewage ponds located at the corner of Golet Road and Escolar Road. The tributary flows through a low-to-moderate gradient, forested area which is predominantly riparian wetland. The stream channel is not well defined in this area. This section has excellent spawning and rearing habitat for coho and cutthroat. Both species have been known to utilize this tributary. The stream flows through a culvert under Snook Road, then alongside a parking lot, through another culvert under an access road, through a ditched section, and under Trigger Avenue via a very long culvert. This is a tortuous path for salmonids to migrate, with little usable spawning or rearing habitat. The following rehabilitation project is recommended for this segment of the TRF tributary:

1. Replace the Snook Road and parking-lot access-road culverts with bridges or arched culverts.

2. Install step-pool dams in the stream to enhance upstream fish passage and provide in-stream habitat.
3. Enhance the riparian zone on the parking lot side with native trees and shrubs. Reclaiming a portion of the parking lot and widening the riparian corridor should also be considered.
4. Install natural stream-bank vegetation for stabilization throughout this tributary segment.
5. Replace the Trigger Avenue culvert with a higher capacity, arched culvert.

Downstream of the Trigger Avenue crossing, the stream is channelized through a wooded area adjacent to the TRF complex. This area between Trigger Street and TRF has natural wetland characteristics but is of poor quality owing to stormwater runoff and encroachment by human activity. The salmonid habitat is also poor, with almost no in-stream LWD, excessive deposition of fine sediment in spawning gravels, and little rearing habitat (pools). The culvert under Sturgeon Street is also problematic from a flow-capacity and fish-passage point of view. A major stream rehabilitation project is recommended for this segment, to include the following:

1. A stormwater treatment wetland should be constructed in the area between Trigger Avenue and the TRF complex. Road, rooftop, and parking-lot runoff from the Trigger Avenue and TRF areas should be routed to this facility.
2. The stream channel should be meandered around this constructed wetland.
3. The stream channel in this section should be enhanced for salmonid passage to the upper reaches. Spawning and rearing should be a secondary goal for this segment.
4. Stream-bank stabilization and revegetation will also be required.
5. New, arched culverts should be installed under Trigger Avenue and Sturgeon Street.

A portion of the current stormwater-piping network for the TRF complex is routed directly into Devils Hole Creek. This practice should be discontinued as soon as possible. From both a water-quality and a runoff-quantity standpoint this is not acceptable. Any runoff not treated by the proposed constructed wetland facility (or all stormwater, if the facility is not built) should be routed to Hood Canal via surface or subsurface conveyance systems along Sturgeon Street. If a treatment wetland is not built, a stormwater pond may be required downhill from TRF (perhaps at the intersection with Sealion Road or before).

North Clear Creek Subbasin

Two branches of the northern tributary of Clear Creek originate within NSB-Bangor's jurisdiction. The northernmost branch has its headwaters in an older part of the base between Luoto and Hunley roads. This is a minor tributary with minimal salmonid habitat potential upstream of the base boundary at Clear Creek Road. The stream is channelized along the road but is more natural downstream of the Clear Creek Road crossing. This tributary also runs under the highway to the east of the base before joining the mainstem of Clear Creek in the broad, flat Clear Creek valley. The main concern for this tributary should be to minimize the quantity of stormwater flowing into the creek. The quality of the water from this portion of the base should be relatively good. The subbasin is partially wooded, with some lawns and administrative buildings. Consideration should be given to constructing a wetland or pond between Sunfish Drive and the base boundary to handle stormwater runoff for this subbasin.

The other branch of the north tributary of Clear Creek has its headwaters in the east-central portion of NSB-Bangor. This subbasin is one of the base's most developed and includes a significant amount of impervious surface area (%TIA in excess of 30). This subbasin also has a variety of land uses, including a retail/commercial complex, high-density housing, administrative buildings, and the Public Works industrial area. The PW industrial area has a centrally located oil/water separator. While this facility is adequate, consideration should be given to augmenting treatment with a multichamber treatment train (MCTT) or a compost media filter system. These systems utilize newer, innovative technology to treat so-called stormwater "hot spots" associated with transportation-related facilities which are primary urban sources of petroleum and metal contaminants (Pitt et al., 1995).

The runoff from this subbasin is piped into a detention facility near the base boundary road. This two-cell pond (with an oil/water separator) serves as the headwaters of the middle tributary of Clear Creek. The outflow from this pond runs under the boundary road and into the stream channel. This tributary of Clear Creek has the potential to support salmonids throughout its length, almost up to the NSB-Bangor boundary. The stream is channelized for about the first kilometer outside NSB-Bangor. Land use in this segment of the creek is rural residential, with several hobby farms encroaching on the stream, resulting in very little riparian corridor. In-stream salmonid habitat is also poor throughout the upper segment of the tributary. It is difficult to determine the specific cause or causes of this in-stream degradation, but encroachment by surrounding land use seems to be a primary contributor. Storm-related flows from NSB-Bangor certainly contribute to the degradation, but the new stormwater-treatment facility appears to be doing a good job of reducing storm-flow peaks and maintaining acceptable water quality. Equally as important as storm-flow effects is the loss of riparian corridor, the lack of in-stream structure (LWD), and the runoff from hobby farms and residential areas in NSB-Bangor. Below this segment, the tributary flows through a section with patches of mature forest and patches of suburban residential land use. In-stream salmonid habitat is generally good throughout this segment and downstream to where this (middle) tributary joins with the south tributary.

It is recommended that NSB-Bangor coordinate with the Kitsap County (SSWM) Stream Team to implement a rehabilitation program for the upper portion of the middle tributary just outside the NSB-Bangor boundary. The area just outside the base (privately owned) would be an ideal location to construct a wetland to support coho rearing and to further treat stormwater flowing from the NSB-Bangor detention pond. Riparian enhancement should also be undertaken, along with fencing of the stream to prevent encroachment by livestock. This project is outside the NSB-Bangor jurisdiction, but would be an excellent opportunity for the base to participate in some community outreach.

East Family Housing/South Clear Creek Subbasin

The headwaters of the south tributary of Clear Creek are dominated by the East Family Housing area. Stormwater from this subbasin is conveyed by pipes and swales into the Trident Lakes treatment facility. These two ponds serve a dual purpose as stormwater detention and recreational facilities (stocked with trout for sport fishing). Runoff from ball fields and roads (Trigger Avenue and Scorpion Avenue) is also routed into Trident Lakes. This facility appears to be working well. Invasive vegetation around the perimeter of the lower lake should be cleared and native trees and shrubs planted. The outlet structures include a base-flow pipe and an overflow spillway. The stream channel downstream of the outlet is armored with quarry rock (for energy dissipation) and is mostly inaccessible to salmonids upstream of the Trigger Avenue crossing. There also appears to be little chance that stocked trout from the lakes can migrate downstream into the creek through this section. The tributary has generally good-to-excellent in-stream habitat downstream of the NSB-Bangor boundary. The south tributary joins the north tributary near the power-line crossing east of Old Frontier Road. The creek then flows under Clear Creek Road and the state highway prior to joining the eastern mainstem of Clear Creek near the Waaga Way crossing.

Local areas of concern (erosion and incision) exist throughout this subbasin, but no major problems were noted. The NSB-Bangor service station, car wash, and auto hobby shop are also located within this subbasin. It is recommended that an MCTT system be installed to replace the oil/water separator currently in use. This is just the type of urban NPS "hot spot" (petroleum products) that this new BMP was designed to treat. These systems tend to perform better than conventional oil/water separators or ponds for treating small impervious areas (Pitt et al., 1995).

West Family Housing Subbasin

The West Family Housing areas are located to the north and south of Thresher Avenue in the west-central portion of the base. This area is dominated by high-density suburban land use. The area has no salmonid-bearing streams and drains directly into Hood Canal via surface swales and subsurface flows. During the design and construction of the newer subdivisions the treatment of stormwater, both quantity and quality, was not given adequate attention. Because of the lack of natural stream channels and the presence of surrounding forests, it appears that stormwater problems were not anticipated. The most common BMP utilized for conveyance of runoff was vegetated and/or armored swales. Most of the housing areas have forest buffers between them, and stormwater is typically routed into these areas. However, owing to the low infiltration capacity of the dominant till soils in this area, the large increase in runoff from impervious surfaces has in many cases overwhelmed the natural capabilities of these forested zones. The result has been several stormwater-related problems that must be dealt with.

The Greenfish Drive/Court subdivision is the smallest of the new developments. Most of the swales in this subdivision frequently have standing water in them, indicating drainage problems. Most of the areas that have this problem contain some exposed soil left over from the construction phase. Regrading and vegetating these areas with native ground cover and coniferous trees should alleviate most of the drainage problems and provide better runoff treatment. Quarry rock should be used in some cases, but only where the swale is steep and prone to erosion. Consideration should also be given to constructing "pocket wetlands" at the confluence of drainage swales to store and further treat runoff. Treatment of quality as well as quantity should be a concern in these residential areas because of the potential use of fertilizers, herbicides, and pesticides. There is an opportunity to construct a wetland treatment facility in the area between the Greenfish subdivision and Thresher Avenue, where stormwater has pooled in a natural depression.

The Grayback subdivision contains both older and newer single-family housing units. There are less stormwater problems in the areas of older housing owing mainly to more established vegetation. The detention areas in this subdivision are not well designed, constructed, or maintained. The swale in the middle of Grayback Circle and the two detention basins along Grayback Drive are in poor condition. These areas have been allowed to become overgrown and are not effectively treating stormwater runoff. It is recommended that these areas be actively managed as stormwater infiltration facilities. This may include removing some nonnative vegetation, regrading, and redesigning outlets.

The runoff swale along the west side of Michigan Street is concentrating flow into a channel instead of encouraging sheet flow into the wooded area behind the houses. All swales should be inspected during storms to see that runoff is not concentrating into high-energy, erosive channels. The old service road between the Florida Drive housing area and the adjacent Alabama Court area is the site of significant erosion. Temporary hay bales have been installed to reduce this problem. The road should be permanently terraced with either rock or logs and revegetated with native trees and ground cover.

There is a no-outlet depression to the east of Sam Houston Drive housing that has evidence of frequent standing water. This is another example of a natural depression being used improperly for stormwater detention. The till soils in this area are not amenable to infiltration, making detention impracticable. This is another good location for a pocket wetland. Alternatively, stormwater collected here could be piped in the established conveyance system and the area regraded and revegetated.

The concrete flume used to collect runoff from the steep slope to the east of Florida Court and Michigan Drive currently drains through an energy dissipater and into a depression at the end of Florida Court. This runoff should be piped out of this open area so that it can be put to more constructive use. By adding fill and regrading this area, it may be possible to expand the existing playground to include a ball field. This runoff, along with the runoff from the west Michigan/Florida Drive swale and the runoff from Alabama Court to the west, should be conveyed into a regional stormwater-treatment facility (pond). This facility has already been partially constructed behind the railroad grade to the west of family housing. An outlet-control structure exists. The area should be cleared of trees and regraded to maximize volume. As a safety measure, this facility should also be fenced. If surface conveyance is chosen for the inlet of this pond, the channel should be hardened (quarry rock) to minimize erosion, and check dams should be installed to reduce flow energy. An energy-dissipation structure on the downstream side of the railroad grade will also be required to prevent erosion at the outlet of the pond.

Runoff from Gudgeon Avenue, Alabama Court, and Georgia Court has begun to incise a significant channel in the area between Georgia Court and Alabama Court. This concentrated runoff originates from a stormwater outfall that runs under Georgia Court. This runoff swale lacks vegetation or energy-dissipation material. The swale should be hardened with quarry rock, installed with check dams, and revegetated. Downstream of this swale is a large area that is suitable for an extended detention-wetland stormwater-treatment facility. The area is currently open and already has an outlet structure adjacent to the railroad grade at the west side. The natural topography of the area would support a detention pond, and the soils are naturally hydric. This facility would service the entire subdivision and could be blended into the community with the inclusion of a nature trail.

DISCUSSION

In-Stream Salmonid Habitat

Historically, the most productive freshwater habitat for salmon and trout was small, lowland streams surrounded by mature, native (primarily coniferous) forests. This region were once a vast network of sloughs, beaver ponds, and complex multichannel streams with a complex mosaic of in-stream habitat features (Maser et al., 1988). As the primary in-stream structural component, large woody debris (LWD) plays a key role in these ecosystems. Urbanization generally leads to more homogeneous, simple stream channels and a loss of habitat complexity. The resultant decrease in habitat quality and quantity leads to less species diversity and a long-term reduction in salmonid abundance (McMahon and Hartman, 1989; Reeves et al., 1993; May, 1996).

In general, the quantity of salmonid spawning habitat (riffles and pools) in NSB-Bangor streams appears to be adequate. For low-gradient (<4%), pool/riffle streams like those found in the Puget Sound lowland region, spawning (riffle) habitat should comprise about 50% (40–60%) of the wetted surface area of the stream (Peterson et al., 1992). For the streams located within NSB-Bangor, all but one section of Devils Hole Creek (the TRF reach) is between 40% and 60% riffles. The upper segment of the middle branch of Clear Creek just outside the NSB-Bangor boundary (downstream of the PW stormwater pond) also lacks spawning habitat. A comparison of NSB-Bangor stream segments with those surveyed during a recent study of PSL streams shows that the NSB-Bangor streams have comparable fractions of spawning habitat (Figure 5). The quantity (surface area) of spawning habitat in PSL streams was found to be adequate for all levels of land usage.

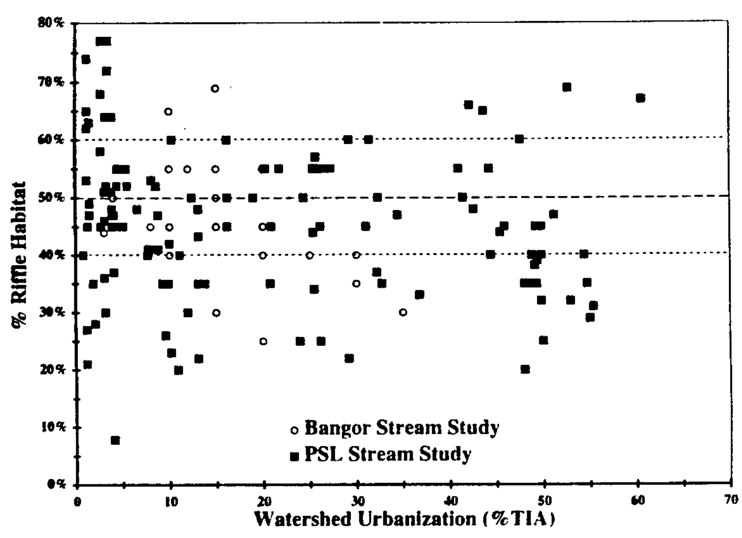


Figure 5. Salmonid spawning habitat (riffles) in NSB-Bangor streams compared with that found in other Puget Sound lowland (PSL) streams during a recent study (May, 1996). Spawning habitat (riffles) should comprise 40–60% of the wetted surface area of the stream (Peterson et al., 1992).

In addition to the quantity of spawning habitat, the quality of existing habitat is also important. The process of spawning site selection by female salmonids is not well understood (Groot and Margolis, 1991). However, there is a combination of factors that determine acceptability for most species. These include the size distribution of substrata particles, water depth, water velocity, gravel permeability (fine sediment content), streambed topography, and protective cover during the spawning process. The exact characteristics of acceptable spawning sites will depend on the species, the size of the female, and the number of acceptable sites available. Within the range of sites where spawning habitat is acceptable, female salmonids appear to apply a second set of criteria to select the optimum site for redd construction. The basis of this site selection is believed to be intragravel flow conditions favorable for incubation and development of embryos (Crisp and Carling, 1989). Suitable intragravel flow conditions occur where the infusion of oxygenated surface water into the streambed is enhanced by a combination of bed topography, in-stream hydraulic conditions, and gravel permeability. Pool tailouts are most often identified as the optimum sites for redd construction because of the natural down-welling flow common to these areas.

Land-use activities such as timber harvesting, mining, grazing, and urban development can have a significant negative impact on spawning habitat, as can catastrophic natural events (e.g., floods or debris flows). Besides scouring and destruction of spawning areas due to high flows, probably the most damaging effect of human activity is the deposition of excessive fine sediment in spawning gravels (Chapman, 1988). To some extent, female salmonids have the ability to modify the streambed to improve the quality of spawning habitat by winnowing fine sediment from the redd during its construction. However, deposition of sediment after redd construction can significantly degrade the quality of the incubating environment. Excessive fine sediment has been associated with reduced survival to emergence of salmonid alevins because of reduced intragravel water flow (Chapman, 1988). The key element is the supply of dissolved oxygen (DO) to the incubating eggs and alevins prior to their emergence from the gravel. The growth and development of salmonid embryos that emerge from the streambed gravels is limited primarily by the supply of intragravel DO (IGDO).

In general, excessive fine sediment was not noted in the stream segments surveyed at NSB-Bangor. The one exception was the middle portion of Devils Hole Creek that flows through the TRF industrial complex. This sediment appears to be coming from two related sources. One is internal to the stream channel: erosion of stream banks due to the combination of high storm flows and the lack of LWD. The other is external to the stream channel: deposition of sediment in the stream by urban stormwater runoff. Correcting this problem will require both rehabilitation of in-stream habitat and construction of stormwater-treatment facilities.

Adequate high-quality *rearing habitat* (pools) is generally recognized as one of the critical factors "limiting" salmonid productivity. This is especially true of winter rearing habitat for juvenile coho salmon (Brown and McMahon, 1987; Reeves et al., 1989; Nickelson et al., 1992). LWD is probably the key component of salmonid rearing habitat in small streams in the PNW and is critical to over-winter survival of juvenile coho salmon (Bustard and Narver, 1975; Brown and McMahon, 1987; McMahon and Hartman, 1989; Nickelson et al., 1992). LWD not only provides habitat structure, complexity, and a high-flow refuge but is a major form of in-stream cover for young fish. Coho, in particular, have a strong preference for pools with a structurally complex (LWD) microhabitat (McMahon and Hartman, 1989). Cutthroat trout appear to prefer a similar rearing habitat, but may be more adaptable to less than ideal conditions (Heggenes et al., 1991). Watershed land use (development) has reduced the quantity of rearing habitat (pools) and degraded pool quality as well (Meehan, 1991). The pervasive and long-term nature of urbanization has been especially hard on in-stream habitat in general and on rearing habitat in particular (Booth and Reinelt, 1993). The PSL stream study showed a significant reduction in the quantity and quality of rearing habitat due to the effects of urbanization (May, 1996).

The fraction of total stream area that was classified as pool habitat (Figure 6) decreased as subbasin development increased, both in the PSL stream study and in the NSB-Bangor stream study. At the same time, the fraction of stream area in riffles (Figure 5) did not significantly change as subbasin development increased. Instead, there was a shift from a "balanced" pool/riffle morphology to a glide-dominant morphology. Glides are intermediate habitats that have characteristics of both pools and riffles but few of the functional attributes of either, providing little cover or flow refuge.

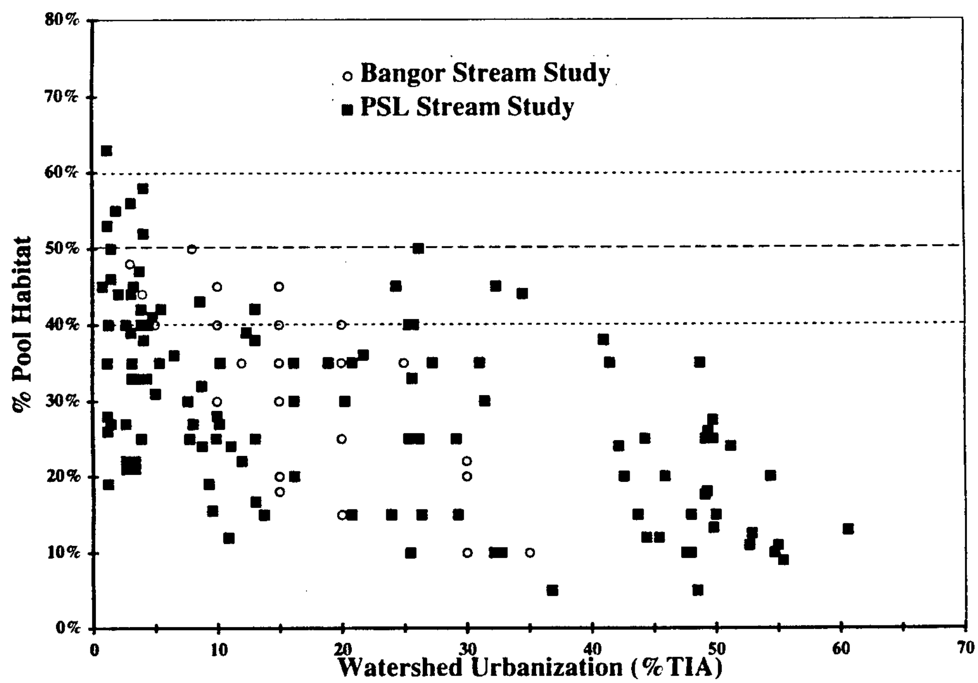


Figure 6. Salmonid rearing habitat (pools) in NSB-Bangor streams compared with that found in other Puget Sound lowland (PSL) streams during a recent study (May, 1996). Rearing habitat (ponds) should comprise 40–60% of the wetted surface area of the stream (Peterson et al., 1992).

Salmonid rearing habitat can also be lost owing to obstructions. Some of the most productive coho rearing habitat is found in side channels, backwater areas, and riparian wetlands (Peterson et al., 1992). Roads built in the floodplain next to streams often disrupt fish access to these off-channel areas by physically isolating them from the main channel. Even if connected by culverts for drainage purposes, these areas are still often inaccessible to juvenile fish. Culverts are generally designed to allow passage by adult spawners and may not have a stream-flow velocity or water level that is proper for juveniles.

Several culverts in NSB-Bangor streams were identified as fish-passage barriers or potential barriers under future flow conditions. These include all three culverts on the SWFPAC tributary of Devils Hole Creek. Also, all three culverts under Sturgeon Street on Devils Hole Creek should be replaced to enhance salmonid migration. The culvert for the firehouse tributary is currently blocking all upstream migration, cutting off about 1 km of spawning and rearing habitat. By far the most significant obstruction to fish passage is the lack of a fish ladder at the outlet of Cattail Creek. This has eliminated any anadromous salmonid runs that existed on this creek prior to development. Installation of a fish ladder should be a high priority.

In addition to the decrease in pool habitat due to development pressures, there was a general lack of pool habitat in all PSL streams, even those with little basin development (Figure 6). This can be traced to the corresponding lack of LWD in PSL streams in general and in urbanizing streams in particular. The relationships between LWD and pool quantity and quality are consistent and, for the most part, quite strong. In PSL streams, LWD is primarily responsible for pool formation (Bisson et al., 1987), provides cover in pools, ensures longevity of stable habitats (Andrus et al., 1988), and promotes a complex rearing habitat (Quinn and Peterson, 1994). In short, LWD provides the in-stream structure necessary to promote habitat diversity (Maser et al., 1988). In the low-gradient streams of the PSL, the reduction in the quantity and quality of rearing habitat is largely due to the combined effects of a change in the basin's hydrologic regime and a decrease in quantity (frequency and size) and quality (mature and coniferous) of LWD. LWD is the "key" component in maintaining a high degree of spatial heterogeneity or habitat complexity (Maser et al., 1988). Perhaps no other structural component is as important to salmonid habitat as LWD. Few studies in the Pacific Northwest have specifically quantified LWD in urban streams, and therefore most comparative data come from studies of forested streams. Nevertheless, the importance of LWD and its functional role in streams draining urbanizing watersheds of the PSL are very much the same as they are in streams draining natural forests in other PNW ecoregions.

Watershed development has significantly affected both the quantity and quality of LWD in PSL urban streams. The quantity and quality of LWD in NSB-Bangor streams are similar to those in other PSL streams. This is true for both LWD frequency and LWD size (volume), although the less developed NSB-Bangor streams generally have larger LWD (Figures 7 and 8).

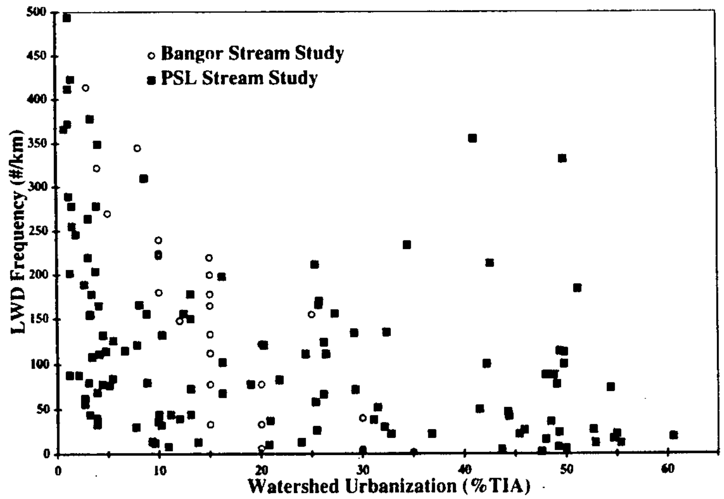


Figure 7. Frequency of large woody debris (LWD) in NSB-Bangor streams compared with that in other Puget Sound lowland (PSL) streams.

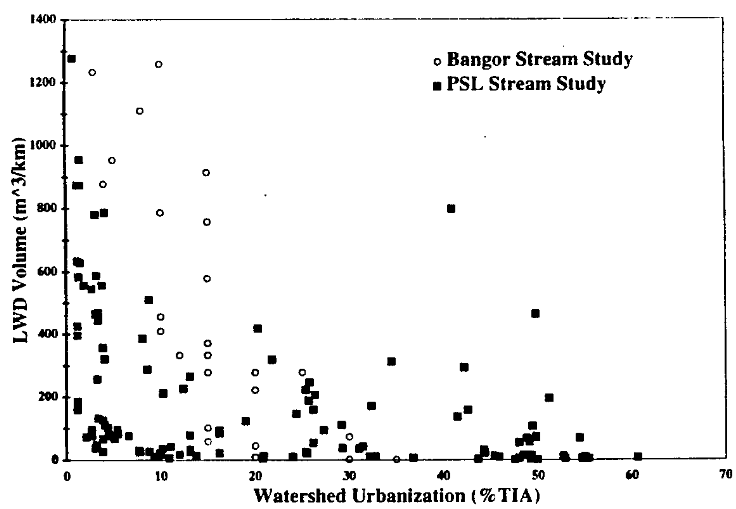


Figure 8. Volume of large woody debris (LWD) in NSB-Bangor streams compared with that in other Puget Sound lowland (PSL) streams.

Even more significant than the decrease in the volume of LWD in urban streams is the lack of large pieces of LWD (Figure 9). "Large" pieces of LWD are defined as those >0.5 m in diameter (Peterson et al., 1992). Large pieces of LWD are a key component of natural forested streams in the PNW and are an excellent measure of LWD quality (Maser et al., 1988). This key LWD provides long-term hydrologic roughness, habitat diversity, and channel stability. Key LWD is especially important in maintaining channel stability through very large storms (Bilby, 1984). This attribute would seem to be extremely important in urban streams, where large flows occur more frequently. In the PSL study, on average, 40% of the LWD in reference stream segments was >0.5 m in diameter (May, 1996). In comparison, a recent study of streams in unmanaged forests (Ralph et al., 1994) found that, on average, 60% of the LWD was >5 m in diameter. That same study found that, on average, about 40% of the LWD in streams in managed (logged) forests was >5 m in diameter. In this respect, the PSL reference streams (%TIA < 5%) appear to be comparable to forest streams with timber being harvested in their watershed. In urbanized PSL streams, on the other hand, only 20% of the total LWD was in the key size range, indicating a more significant loss of "key" LWD due to urbanization than due to logging. Other measures of LWD quality include the type (coniferous or deciduous), the species (cedar is considered best), and the age of the wood.

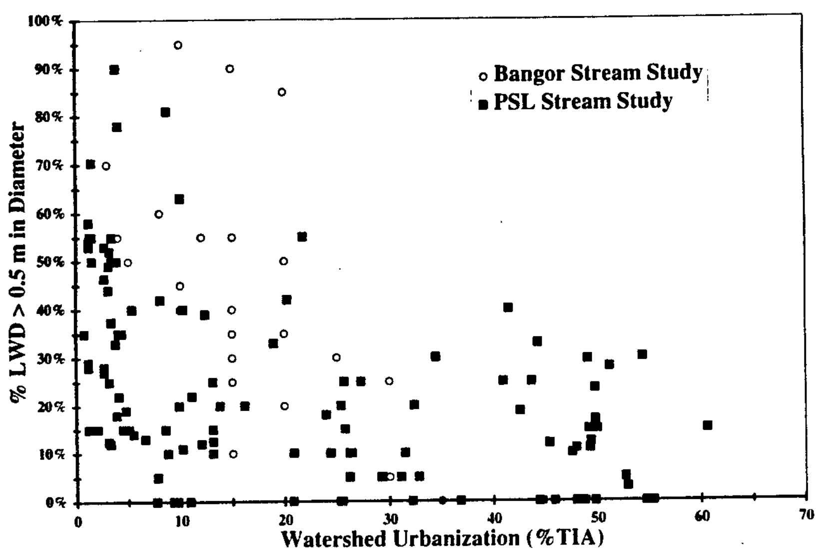


Figure 9. Percentage of key (>5-m-diameter) large woody debris (LWD) in NSB-Bangor streams compared with that in other Puget Sound lowland (PSL) streams (May, 1996).

The loss of LWD, along with the increased flows due to basin urbanization, can have a negative feedback effect on the remaining in-channel LWD, causing further losses and continued "unraveling" of the natural ecosystem. The relative significance of high flows and decreased LWD is often difficult to distinguish. The lack of LWD in urbanizing streams of the PSL also leads to degradation of in-stream physical conditions (Booth, 1991). Channels experience greater scouring, erosion, and lateral instability; the flux of sediment is greater and more closely tied to individual high-flow storm events; and the habitat diversity of natural streams is replaced by a uniform channel profile and cross-section (glide-dominant). Many of these effects are also a product of the increased discharges that normally accompany urbanization, but the loss of flow dissipation by LWD is certainly significant (Bisson et al., 1987; Ralph et al., 1994; May, 1996). The mechanisms by which LWD is lost from urban stream channels are similar to those in streams affected by timber harvest but, in general, are more pervasive and ongoing.

Probably the most widespread and most difficult to detect mechanism for LWD loss in urban streams is human activity. This is also a loss mechanism that is unique to urban streams. After timber harvesting there is little human contact with the riparian buffer, but in an urban setting there can be nearly continuous human intervention. This affects not just in-channel LWD-related processes, but also LWD recruitment from the riparian zone. Local flood-control concerns have also driven removal of some in-channel LWD. Mobile LWD often becomes lodged in culverts or jammed under bridges at road crossings, necessitating removal by utility crews. Culverts are especially problematic in that natural redistribution of LWD downstream is nearly impossible if culverts are in place. Landowners also may remove in-stream "obstructions" for drainage or flood-control purposes. Owing to the encroachment of development, this in-stream removal problem is further exacerbated by removal of LWD from riparian areas and/or the loss of recruitment potential from riparian forests themselves. Removal of LWD for "aesthetic" reasons is also a major consideration. Gregory and Davis (1993) found that people had a strong preference for "natural" streams but that channels without in-stream LWD were preferred to those with debris. Despite the ecological advantages of LWD, it seems that people find streams with natural LWD "messy." It was also found that most people tend to prefer riparian areas that consist of natural but not "wild" vegetation (Mosley, 1989; House and Sangster, 1991; Gregory and Davis, 1993). Wood cutting for firewood and to "prevent" wind-fall home damage is also a factor.

Washout is also a major mechanism for LWD loss from urban streams. As has been discussed, watershed development leads to an increase in peak discharge (Booth, 1991). The duration of floods also may increase by an order of magnitude or more (Booth, 1991). The frequency of dominant discharges (major transport events) can also increase dramatically (Booth, 1991). In addition to increasing sediment transport, these flows are also capable of moving all but the largest LWD. The change in the hydrologic regime also tends to expand the cross-sectional profile of the channel through lateral expansion and/or incision (Booth, 1990). This may expose more individual pieces of LWD to high flows, as well as undermine and destabilize previously anchored or buried LWD, increasing the chance of movement or washout. Bedload stored behind LWD also becomes susceptible to transport, increasing sedimentation and scouring of the downstream channel.

Stranding is a related mechanism of LWD loss in urban streams and is caused by the same high flows as washout. Because of the combined effects of channel enlargement and incision, LWD may become beached outside the area of active stream flow. Primarily because of the increased sediment transport of urban streams and the lack of bedrock to control stream gradients in the PSL, down-cutting (incision) of the streambed often results, especially in small tributary streams. Therefore, LWD can become suspended above the streambed, where it is ineffectual in providing any flow resistance. This further loss of flow resistance typically accelerates the incision process and may result in catastrophic washout of LWD as well. Channel widening in urban streams can also leave LWD "high and dry" on the channel margins, resulting in additional loss of flow resistance, in-stream habitat, and sediment storage. Both channel incision and channel widening were observed in PSL streams.

While all these LWD loss mechanisms are sometimes assumed to be gradual and reversible in nature, the experiences of forest resource managers indicate otherwise. Bilby and Ward (1991) found that human activity in the riparian zone led to rapid and generally severe changes in the structure and processes of stream channels. Observations of urban streams in the PSL confirm this basic "unraveling" of the system. The rapid decline in in-stream habitat quality and quantity that accompanies the onset of basin development supports this contention. That over 100 years is required for a mature, natural riparian forest to be reestablished after logging (Bilby and Ward, 1989) is even more reason to protect and nurture wide riparian corridors surrounding urban streams. For optimum LWD recruitment, riparian buffers should consist of a mature forest dominated by conifers.

Figure 10 compares the QHI scores of NSB-Bangor streams and other PSL streams. As with several of the quantitative habitat measures (LWD, pools, and riffles), the QHI scores suggest that there is a initial dramatic decline in habitat quality as basin development (%TIA) increases above 5–10%. In other words, the effects of human intrusion on the stream ecosystem become evident even during the subtle shift from largely undeveloped to rural watershed land use. A similar precipitous decline in habitat quality is often seen for other land-use activities, timber harvesting being the most notable. Pin pointing the exact stressors responsible for this drop in habitat quality is difficult; however, a multimetric index such as the QHI is able to detect this change because of its assessment of several variables. The QHI is also able to differentiate between the "best" and "worst" stream segments and as such provides a useful first-cut tool for assessing stream quality. That the QHI results for the mid-range of basin development (suburban) were quite variable should not be surprising. The complexity of stream systems and the variety of impact variables make accurate assessment difficult, on either a quantitative or a qualitative basis.

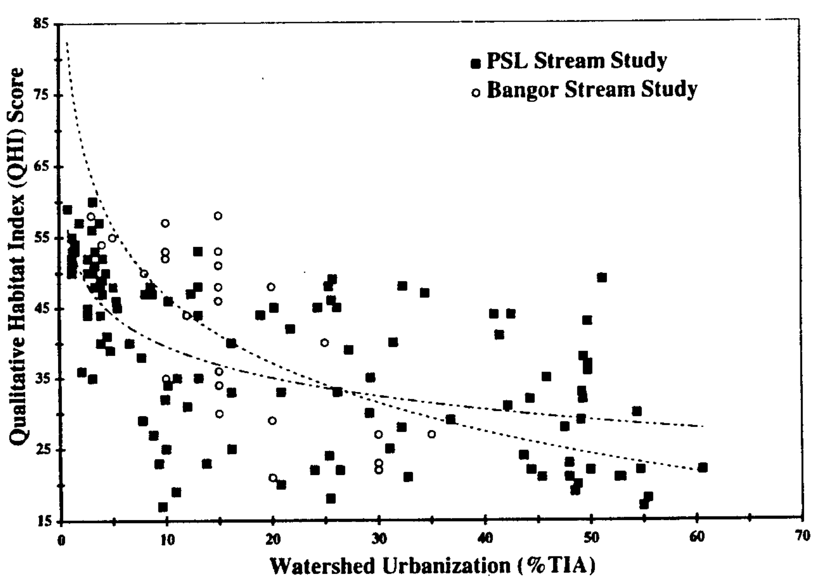


Figure 10. Qualitative habitat index (QHI) scores for NSB-Bangor streams compared with those for other Puget Sound lowland (PSL) streams.

Resource managers making an initial screening of a stream may not want to undertake a full-blown habitat assessment for a variety of reasons. The QHI (or a similar survey) performed by trained personnel can provide an initial summary of the positive and negative characteristics of a particular section of creek. The QHI can identify areas to concentrate on during subsequent quantitative surveys or can be used for periodic assessment to identify emergent problems. There is a close relationship between the QHI and various quantitative habitat measures, making it a good first step in the overall assessment process. Many other states and agencies utilize some form of qualitative habitat assessment. Most use it in conjunction with biological sampling (Plafkin et al., 1989; Rankin, 1989; Maxted et al., 1994). In these situations, the QHI is typically used to put the macroinvertebrate samples in context and give resource managers a starting point for linking biological integrity and stream quality. Using the QHI as the sole habitat-assessment tool or using it as the sole basis for making management or restoration decisions is probably not appropriate. Some quantitative methods are still required.

Based on the findings of the PSL stream study (May, 1996) and a review of literature pertaining to natural, forested lowland streams in the PNW (Peterson et al., 1992), a set of "target" conditions is proposed for NSB-Bangor in-stream physical habitat parameters (Table 2). A multilevel approach to habitat quality is used so that NSB-Bangor resource managers can tailor their level of effort to meet the expectations and feasibility of the situation. Annual in-stream habitat assessments (using the QHI as a minimum) should be instituted to monitor trends in salmonid habitat quantity and quality and to provide a baseline for rehabilitation projects. These surveys should also be used to evaluate BMP effectiveness and to guide future stormwater-mitigation efforts. Permanent survey reaches can also be established to provide for better comparison between year-to-year surveys. Surveys can be done by NSB-Bangor personnel, by local tribal groups, or with the assistance of the Kitsap County Stream Team.

Chemical Water Quality

Analysis of data taken as part of the current Stormwater Pollution Prevention Plan (SWPPP) indicates that chemical composition of the water is acceptable by US EPA and Washington Department of Ecology standards. The water-qualilty data included samples from outlets of stormwater-treatment facilities as well as stream outfalls (receiving waters). Similar results were found for urban stormwater (Chandler, 1995) and in-stream storm flows (Bryant, 1995) for a number of streams in the Puget Sound region (see Tables 3 and 4). In general, violations of chemical water-quality standards are found on a regular basis only in highly developed watersheds (May, 1996).

The stormwater and receiving-water sampling plan described in the NSB-Bangor SWPPP appears to be adequate. Emphasis should be placed on sampling during storms rather than adhering to a strictly periodic sampling schedule. Critical stormwater constituents are listed in Table 5. In accordance with the Clean Water Act, priority in sampling and analysis should be given to constituents that have the greatest impact on both human health

Table 2. Target conditions for in-stream habitat in PSL streams.

In-Stream Habitat Parameter	Salmonid Life-Phase Influenced	Indication of Poor Habitat Quality	Target for Fair Habitat Quality	Target for Good Habitat Quality
Pool Habitat (Surface Area)	Rearing	< 30%	30–50%	> 50%
Pool Frequency (BFWs Between Pools)	Rearing	> 4	2–4	< 2
LWD Frequency (BFWs Between LWD)	Rearing	< 1	1–2	> 2
Key LWD (Diam. > 0.5 m)	Rearing	< 20%	20–40%	> 40%
Pool Cover	Rearing	< 25%	25–50%	> 50%
IGDO/DO Interchange	Spawning and Incubating	< 60%	60–80%	> 80%
Pebble Count D10 (mm)	Spawning and Incubating	< 3 mm	3–5 mm	> 5 mm
Fine Sediment (<0.85 mm)	Spawning and Incubating	> 20%	15–20%	< 15%

LWD = Large woody debris
BFW = Bank-full width
IGDO = Intragravel dissolved oxygen

Table 3. Typical urban runoff (stormwater) pollutant levels for the Puget Sound lowland (PSL) region (Chandler, 1995).

Constituent	PSL Mean	PSL Median	NURP Median
TP (μg/L)	320	240	330
TSS (mg/L)	93	81	100
TZn (μg/L)	210	180	160

TP = Total phosphorous; TSS = total suspended solids; TZn = total zinc; NURP = National Urban Runoff Program

Table 4. Mean concentrations of in-stream pollutants during storm-flow events in Puget Sound lowland streams (Bryant, 1995).

Constituent	Mean	Median	Maximum
TP (μg/L)	118	94	419
TSS (mg/L)	55	17	820
TZn (μg/L)	27	15	139

TP = Total phosphorous; TSS = total suspended solids; TZn = total zinc

Table 5. Critical stormwater constituents (from Makepeace et al., 1995).

Constituents Affecting Human Health	Constituents Affecting Aquatic Biota
Total Suspended Solids (TSS)	Total Suspended Solids (TSS)
Metals (Aluminum, Chromium, Lead, Iron, Manganese, and Mercury)	Metals (Aluminum, Cadmium, Chromium, Copper, Lead, Mercury, Iron, and Zinc)
Organics (Pesticides and Herbicides)	Organics (Pesticides and Herbicides)
Polycyclic Aromatic Hydrocarbons (PAHs)	Temperature
Fecal Coliform Bacteria	Polychlorinated Biphenyls (PCBs)
Enterococci Bacteria	pH
Tetrachloroethylene (TCE)	Nutrients (Phosphorus and Nitrogen)
	Ammonia
	Dissolved Oxygen (DO) and Intragravel DO
	Chloride

and in-stream biological integrity (TSS, metals, and organics). When the water-treatment facilities are monitored for effectiveness, nutrients (phosphorus and nitrogen) should also be analyzed. NSB-Bangor may wish to consider purchasing a commercially available automatic sampler to make this task less labor intensive. Base-flow monitoring of streams within NSB-Bangor should be done on a monthly basis in order to develop a database for analyzing future trends. It is recommended that temperature, pH, conductivity (total dissolved solids), dissolved oxygen (DO), and total suspended solids (TSS) or turbidity be the only parameters monitored on a periodic basis during base-flow conditions. These parameters are all easily measured in the field using inexpensive meters or test kits.

Riparian Conditions

The riparian forest was analyzed on a qualitative and quantitative basis, using aerial photographs and ground surveys. The relationship between the width of the riparian buffer and the level of development was examined on both a watershed and a stream-segment scale. The minimum effective width of the riparian buffer was considered to be 10 m (30 ft), and a width of 30 m (100 ft) was generally considered to meet most functional requirements (Johnson and Ryba, 1992). These two widths were used as the primary benchmarks of riparian integrity.

A strong correlation was observed between riparian buffer width and basin imperviousness (%TIA). The fraction of riparian buffer >30 m wide (Figure 11) was typically over 70% for the undeveloped streams (%TIA < 5%). The fraction of riparian buffer <10 m wide (Figure 12) was also strongly correlated with urbanization. In general, in undeveloped reference streams (%TIA < 5%), less than 10% of the riparian buffer was <10 m wide. As urbanization increased, encroachment on the riparian zone increased proportionally. Taken together, these two parameters (% > 30 m and % < 10 m) define the lateral integrity of the riparian buffer.

Each segment of the riparian buffer was also examined qualitatively based on the dominant land use within 30 m of the stream. Mature forest, young forest, and wetlands were considered "natural" land use as opposed to predominantly residential or commercial use. From an ecological perspective, mature forest and/or riparian wetlands are the two most desirable natural riparian conditions (Gregory et al., 1991). Figure 13 compares the percentage of riparian corridor in NSB-Bangor and other PSL watersheds that is composed of forest or riparian wetland. Only in the undeveloped reference streams (%TIA < 5%) is most of the riparian corridor in a natural condition. In addition, no urbanized streams have retained more than 25% of their natural floodplains.

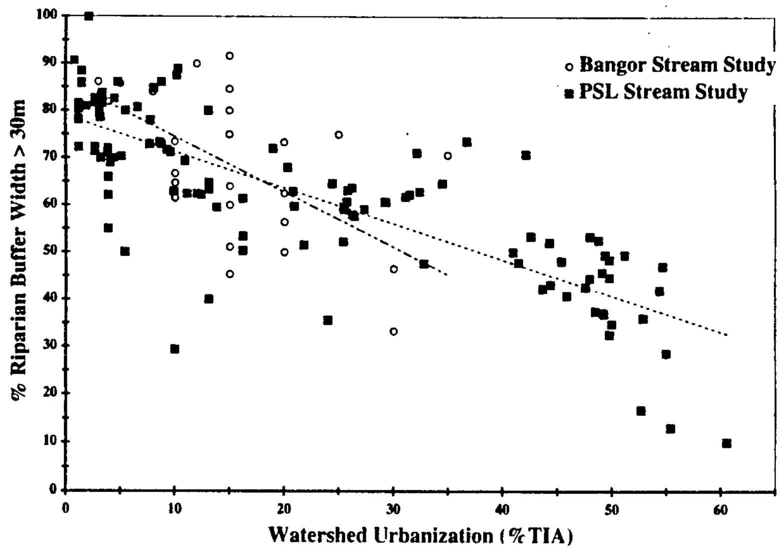


Figure 11. Riparian buffer integrity in NSB-Bangor study streams compared with that in other Puget Sound lowland (PSL) streams (May, 1996).

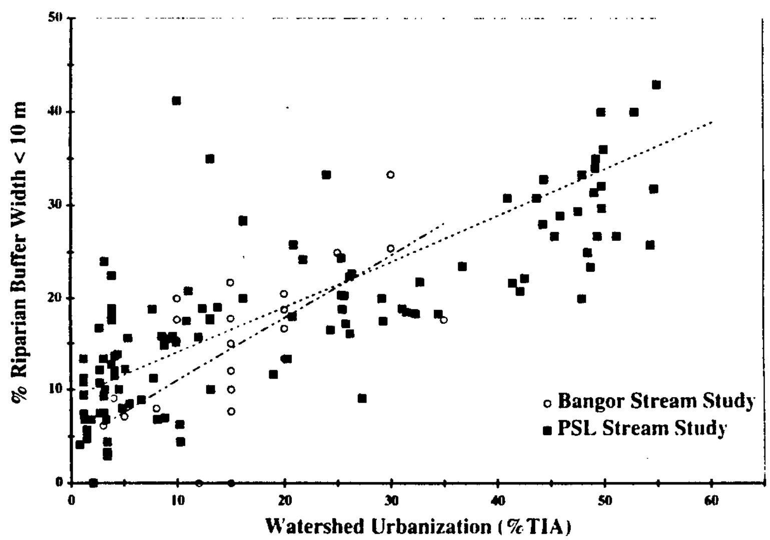


Figure 12. Riparian buffer encroachment in NSB-Bangor streams compared with that in other Puget Sound lowland (PSL) streams (May, 1996).

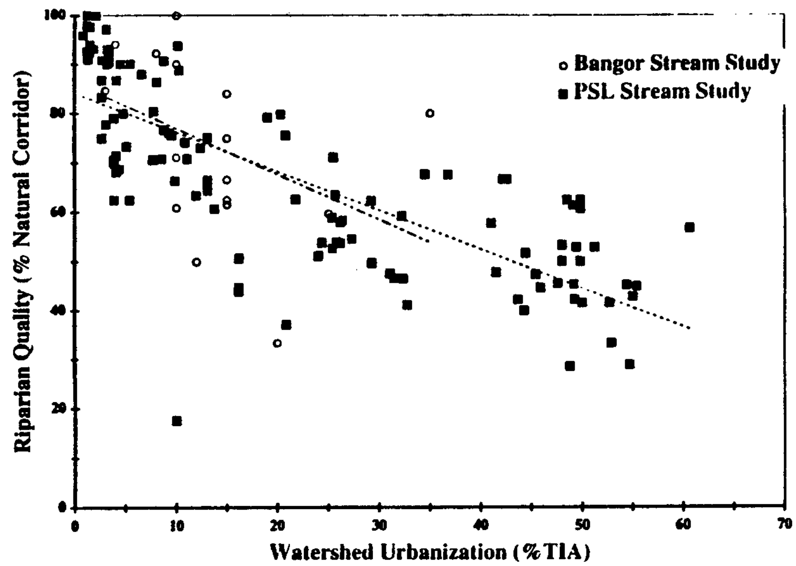


Figure 13. Riparian buffer quality in NSB-Bangor streams compared with that in other Puget Sound lowland (PSL) streams (May, 1996).

As a measure of the longitudinal continuity of the riparian corridor, the number of breaks in the riparian zone was tallied for each stream segment surveyed. Breaks, for the purpose of this study, were considered such things as road crossings, pipelines, and utility right-of-ways. The number of breaks was normalized to a per kilometer basis using stream segment length for comparison purposes. There was a strong, direct relationship between breaks (per kilometer) in the riparian corridor and urbanization level (see Figure 14). In

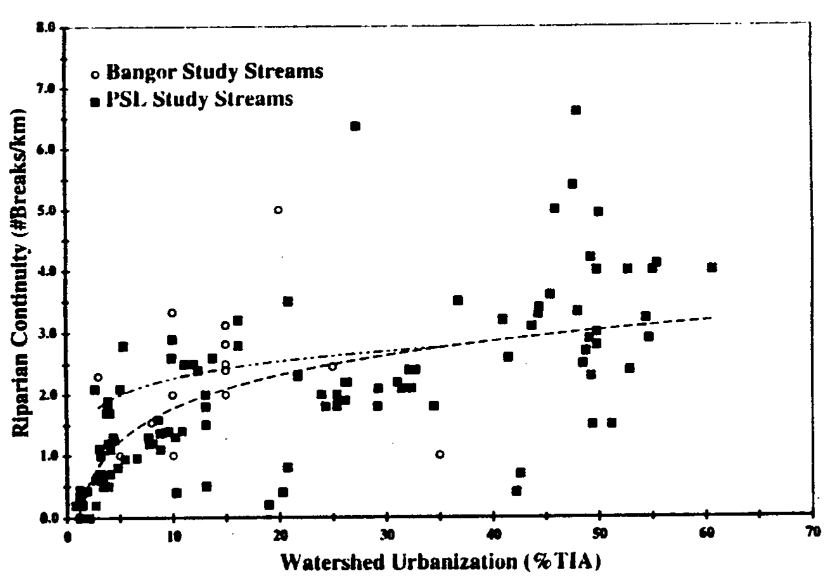


Figure 14. Riparian corridor continuity in NSB-Bangor streams compared with that in other Puget Sound lowland (PSL) streams (May, 1996).

general, the less impacted streams tended to have less than two riparian breaks (stream crossings) per kilometer of stream length. As would be expected, the number of breaks (mostly road crossings) is closely linked to the density of roads in the basin. As with lateral riparian integrity and riparian quality, longitudinal riparian integrity is strongly correlated with the overall level of urbanization (%TIA), making riparian quantity and quality excellent indicators of development impact. Unfortunately, this close association between riparian condition and basin development, as well as the lack of outliers (see Figure 1), makes analysis of the riparian mitigation potential difficult.

Road Culverts

Culverts serve two main purposes: to provide a conveyance route under the roadbed and to allow fish passage. If designed and installed properly, a culvert can perform both tasks concurrently under a full range of flow conditions. The culvert must be sized and sited correctly to allow downstream passage of water, bedload, and debris (LWD). Upstream development subsequent to installation of a culvert can create flows (water and bedload) far in excess of the structure's design capacity and block fish passage. In the PNW fish passage includes upstream migration of anadromous and resident salmonids during the spawning season, as well as movement (upstream or downstream) of juveniles or resident adults at various times of the year (Reeves et al., 1989; Heggenes et al., 1991; Nickelson et al., 1992).

A barrier to fish passage is defined as any physical feature in the stream that causes excessive delay in fish migration and/or abnormal expenditure of energy during any life stage of the fish (Evans and Johnston, 1980). Barriers can be natural or artificial. In addition, they can be partial, total, or temporary in nature. The most common man-made barriers to fish passage found in the PNW are road culverts. In 1994, the Washington Department of Fish and Wildlife (WDFW) estimated that over 2000 culverts in the state were significant barriers to salmonids and that over 3000 miles of habitat had been lost owing to these culverts. Kitsap County alone has identified over 20 culverts that are fish-passage barriers. Correcting these culvert problems is a high priority in Washington State.

Typical fish-passage problems associated with culverts include the following (see Figures 15–19):

- an excessive drop at the culvert's outlet (so-called "perched" culverts)
- too high a velocity at the culvert's inlet (fish unable to exit)
- depth and/or velocity problems within the culvert during flow extremes
- accumulation of debris at the culvert's inlet (inadequate capacity)
- misalignment of the culvert with respect to the stream channel
- too long a culvert (beyond the endurance of the fish)
- culverts installed at too steep a gradient (resulting in high flows)
- culverts with no resting pools at inlets or outlets
- stream-bank erosion, scouring, and deposition due to poor culvert road fill.

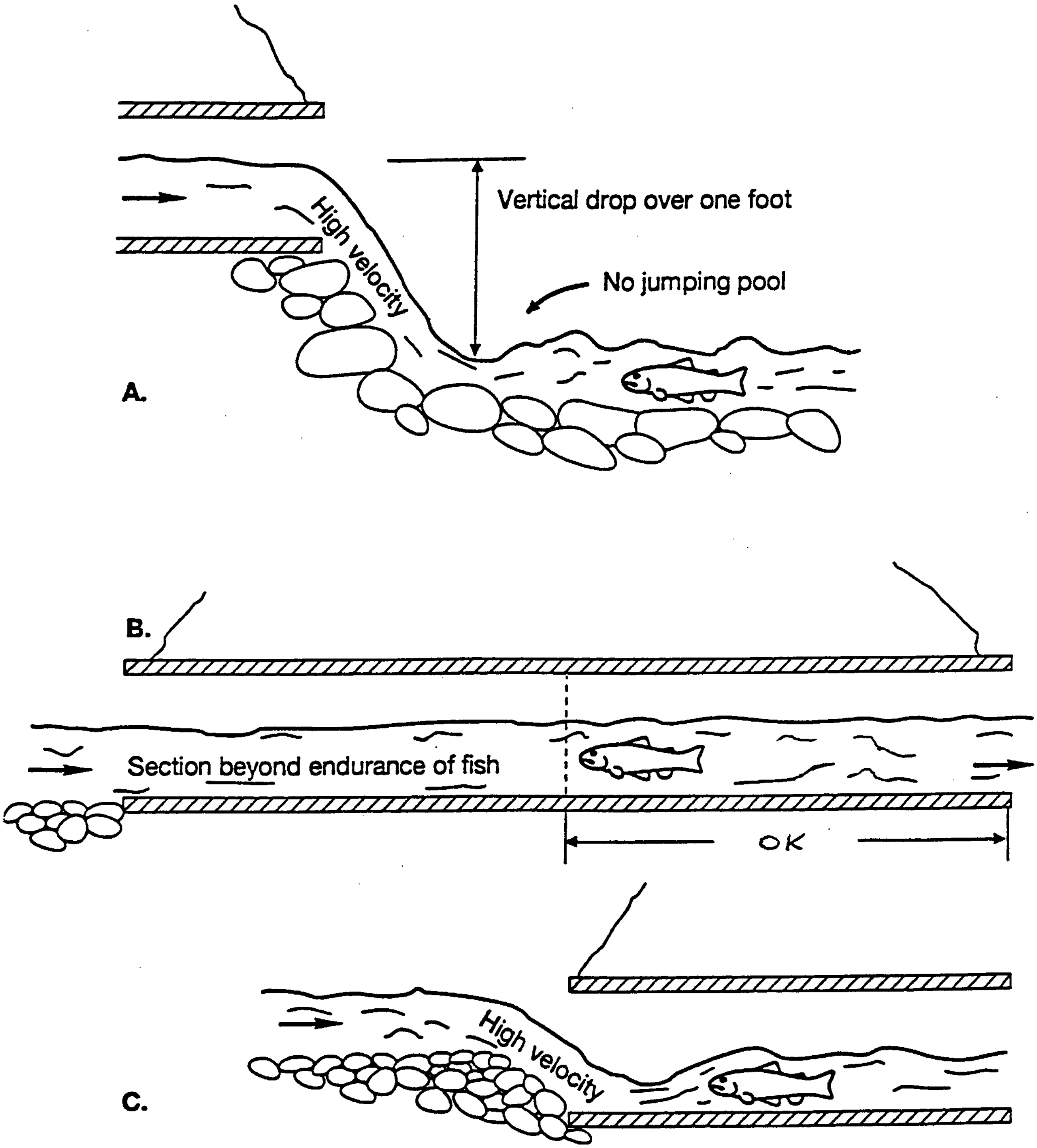
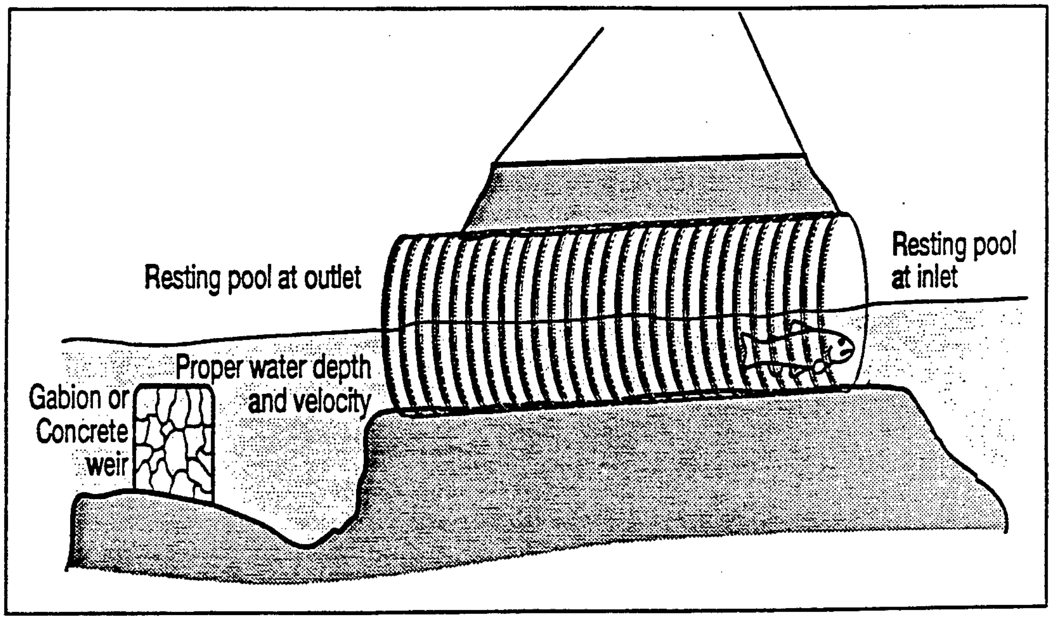
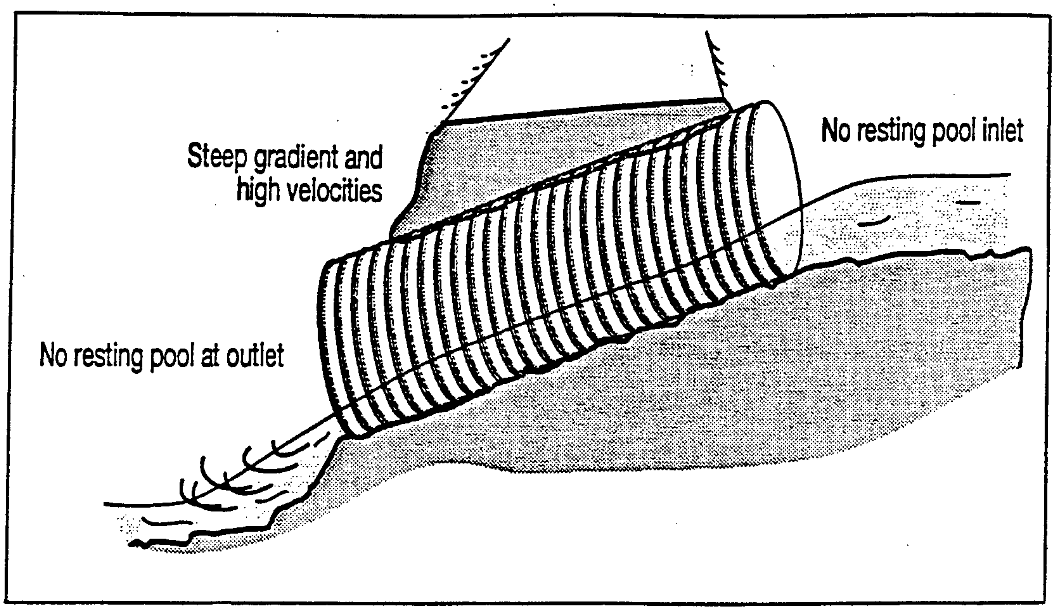


Figure 15. Culvert passage problems (from Evans and Johnston, 1980). A. Perched culvert. B. Culvert length beyond endurance of fish. C. Culvert inlet velocity too high.



Installation suitable for fish passage.



Installation unsuitable for fish passage.

Figure 16. Culvert installations suitable for fish passage (top) and unsuitable for fish passage (bottom) (from Evans and Johnston, 1980).

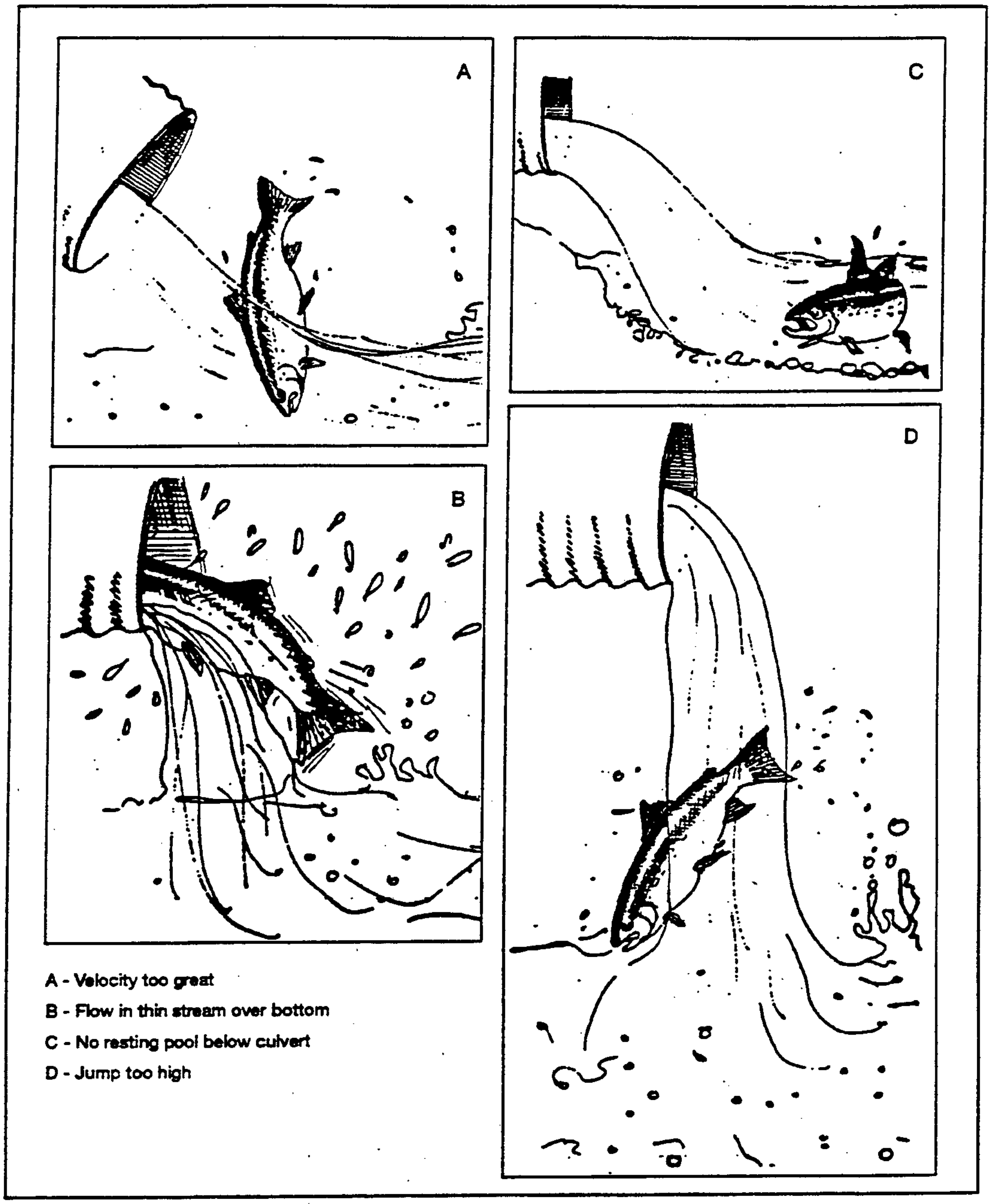


Figure 17. Common conditions that block fish passage (from Evans and Johnston, 1980).

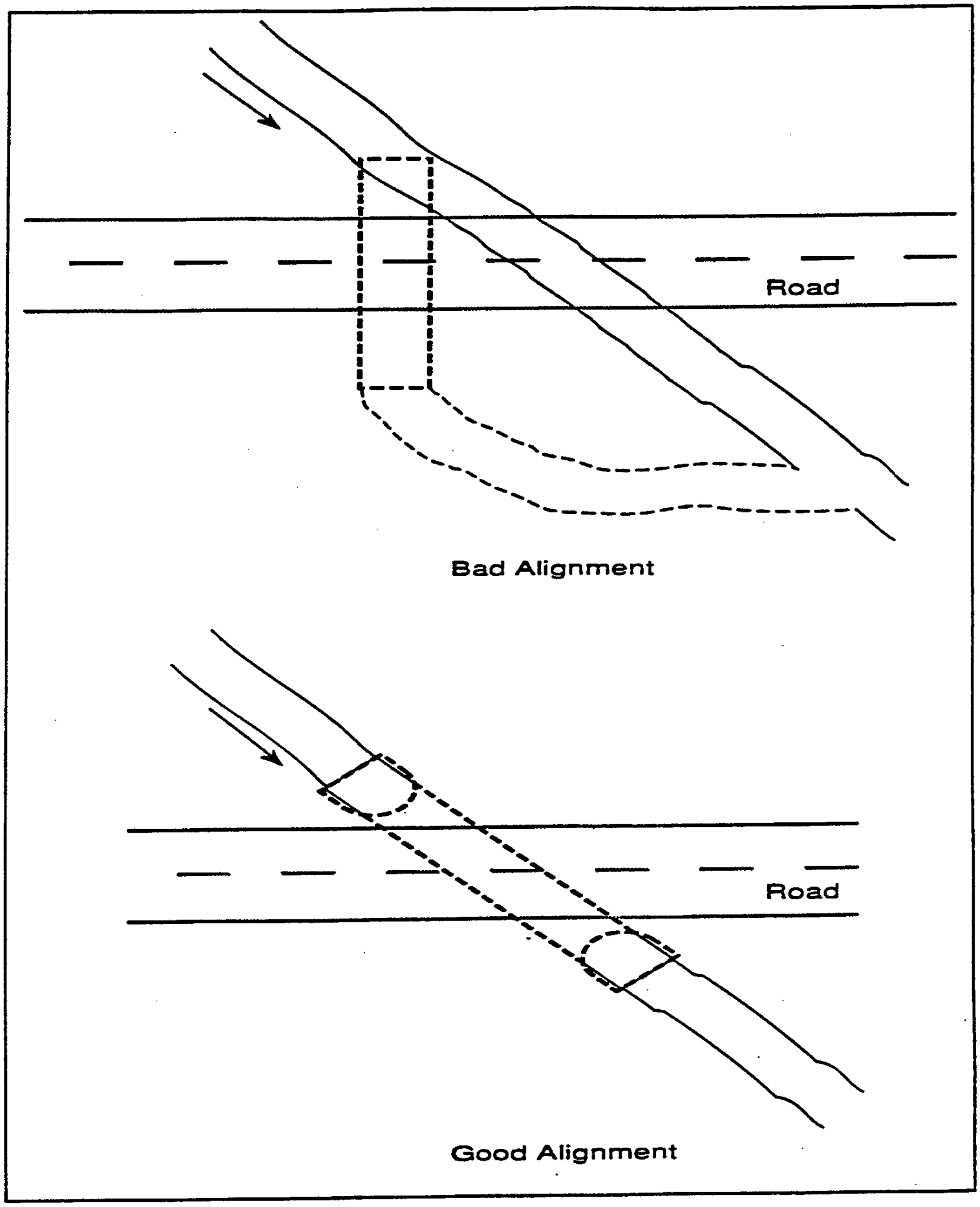


Figure 18. Locating culvert crossings (Baker and Votapka, 1990).

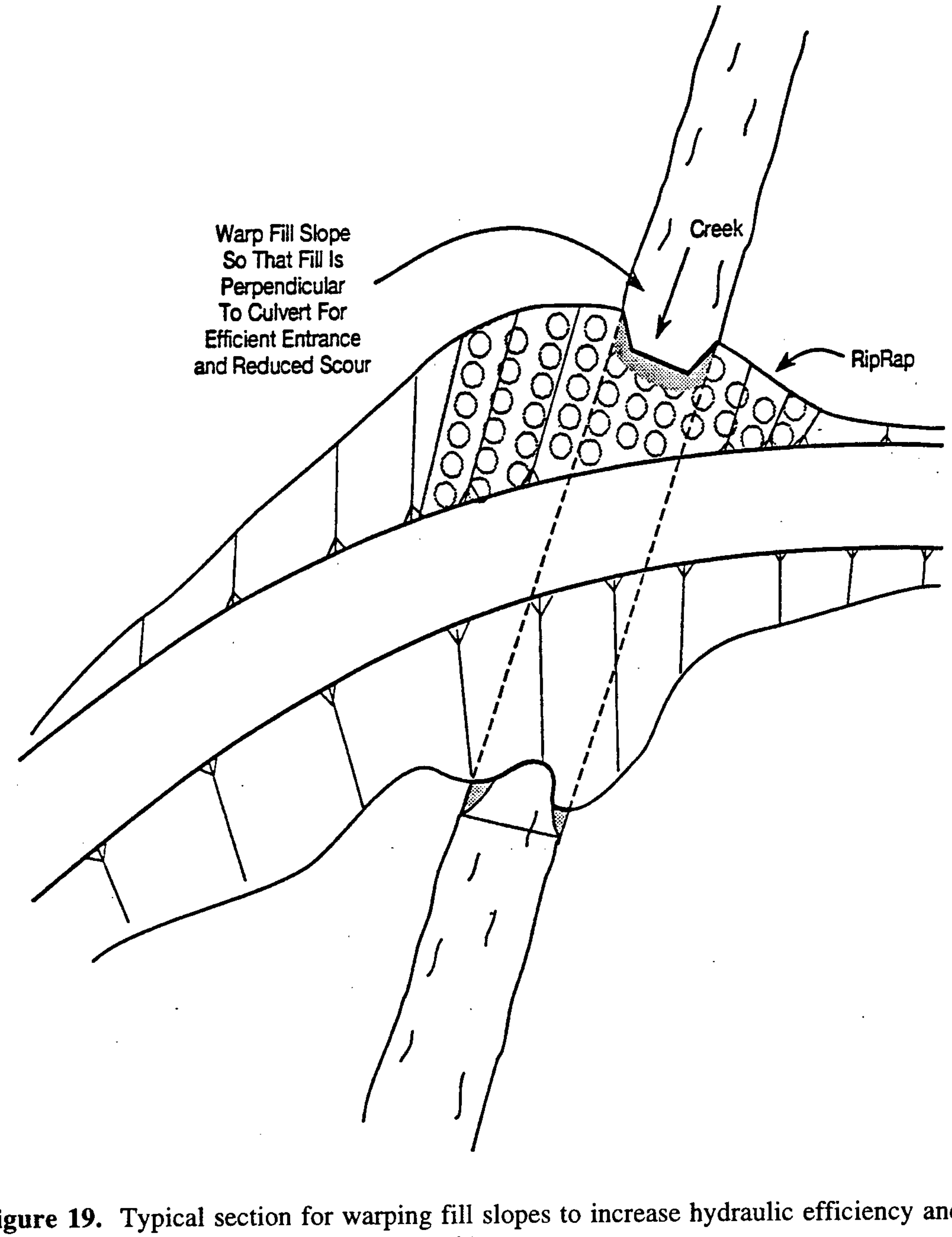


Figure 19. Typical section for warping fill slopes to increase hydraulic efficiency and to reduce scouring (Baker and Votapka, 1990).

As part of this study, all culverts on NSB-Bangor were surveyed and compared with the WDFW design criteria for fish passage of coho and chum salmon and cutthroat trout (Table 6). The following culverts were identified as fish-passage barriers (either partial, complete, or temporary):

- Three (3) culverts under Sturgeon Street on Devils Hole Creek
- The culvert under Trigger Avenue on the TRF tributary of Devils Hole Creek
- Three (3) culverts on the SWFPAC tributary of Devils Hole Creek.

All of these culverts are included in the recommended habitat-enhancement projects (Appendix A). The culverts under Sturgeon Street and Trigger Avenue are undersized for current flow conditions, too long for many fish (including juvenile coho) to traverse, blocked by sediment and debris, and/or misaligned with their respective stream channels. Replacement of these culverts should be a high priority. The culverts on the SWFPAC tributary are all undersized and perched. Replacement of these culverts has a lower priority because there is less potential for utilization by fish and less habitat is available upstream.

Table 6. Washington Department of Fish and Wildlife fish-passage design criteria for culverts.

Criterion	Adult Trout > 6 in. (150 mm)	Adult Pink and Chum Salmon	Adult Chinook, Coho, Sockeye, and Steelhead
Max. Velocity (fps)			
Culvert Length, 10–60 ft	4.0	5.0	6.0
Culvert Length, 60–100 ft	4.0	4.0	5.0
Culvert Length, 100–200 ft	3.0	3.0	4.0
Culvert Length, >200 ft	2.0	2.0	3.0
Min. Flow Depth (ft)	0.8	0.8	1.0
Max. Hydraulic Drop (ft)	0.8	0.8	1.0

Biological Integrity

The PSL stream study (May, 1996) showed a close link between watershed development and changes in the disturbance regime of the aquatic ecosystem. Strong relationships between watershed conditions, including basin imperviousness and riparian corridor integrity, and in-stream, physical habitat characteristics were also demonstrated. Finally, a direct connection was established between watershed conditions and biological integrity, as well as between in-stream habitat conditions and biological integrity. The results of the Bangor stream study were nearly identical. Devils Hole Creek and Cattail Creek were sampled for macroinvertebrates during September 1997. The portions of Clear Creek located within NSB jurisdiction were not suitable for biological sampling, and thus no data exist for this stream. Macroinvertebrate sampling was conducted downstream of NSB-Bangor (for an unrelated project) during October 1997. These data were not available for inclusion in this analysis. The results for both Devils Hole Creek and Cattail Creek are shown in Figure 20 along with the results of the PSL stream study. Both creeks fit well within the range of data found in the PSL study and have "good" biological integrity.

It is strongly recommended that a biological monitoring plan be established for the NSB. This plan should utilize benthic macroinvertebrates as the indicator organisms and should utilize a multimetric index for analysis. The benthic index of biotic integrity (B-IBI) developed by Karr (1996) for the PNW or the US EPA protocols (Plafkin, 1989) are recommended.

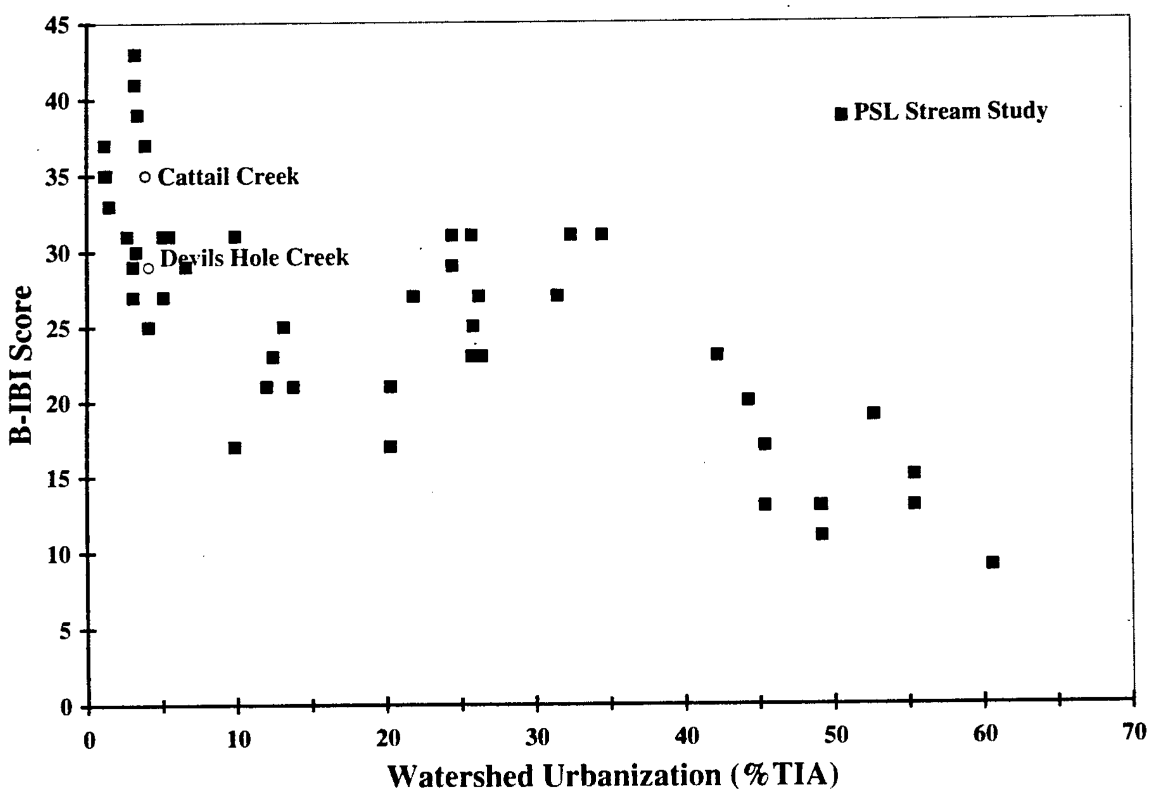


Figure 20. Biological integrity of Cattail Creek and Devils Hole Creek compared with results of the PSL stream study (May, 1996), as measured by the benthic index of biotic integrity (B-IBI). The higher the score, the better the biological integrity.

STORMWATER BEST MANAGEMENT PRACTICES

This section summarizes the capabilities and limitations of the current generation of stormwater best management practices (BMPs). It is important to keep in mind a few major assumptions when considering use of BMP technology:

- Most BMPs are designed for either quantity control or quality treatment of stormwater runoff; few can do both effectively. The designer must decide which goal is most important and weigh the trade-offs of various treatment systems.

- Not all BMPs can reliably provide high levels of removal for both particulate and soluble pollutants. In most cases, the main concern is with particulates because of the long-term, negative impacts of sedimentation on in-stream habitat and aquatic biota. The current pollutant removal rates for various BMPs are summarized by Schueler (1997). These data are quite variable and depend on both the design and maintenance of the BMP facility.

- The most effective (and cost effective) method of stormwater control is *source reduction*. If runoff is prevented and/or treated on site, then stormwater treatment will not be an issue. *Reduction of impervious surfaces* is one of the most effective methods of source reduction in the PNW (City of Olympia, 1994).

- The longevity and overall effectiveness of some stormwater BMPs are unknown owing to limited use, lack of long-term studies, changes in design criteria, and poor construction. In addition, relatively little information is available on cost effectiveness.

- No single BMP option can be applied to all development situations, and all BMP options require careful site assessment prior to the design stage, as well as close supervision during the construction process.

- Several BMPs can have significant secondary environmental impacts if site assessment is not thorough, construction is not monitored, or facilities are not maintained. The extent and nature of these potential impacts are very site specific.

- Future enhancement and/or retrofitting of stormwater BMPs will probably be required as research identifies current inadequacies and new technologies become feasible.

- While structural BMPs are quite effective, nonstructural (natural) methods should be utilized to enhance or complement stormwater treatment and control facilities whenever possible. The "best" method of stormwater control is to allow ecosystems to function naturally, by instituting a *zero-discharge policy* for stormwater runoff with respect to natural surface waters (streams, lakes, and wetlands).

- Maximum application of preventive BMPs should be given high priority in the overall watershed management plan. Ideally, structural BMPs should be used only as a backup for preventive BMPs. Preventive BMPs are preferred because of their potential to avert the release of pollutants, which can be difficult or expensive to recapture once they have become part of stormwater runoff. Unfortunately, the engineering focus has emphasized structural solutions at the expense of preventive measures. Therefore, up to now the effectiveness of preventive methods has not been fully tested. Preventive BMPs include source control measures, street sweeping, and on-site (passive) stormwater treatment.
- Management and source control of potential pollutants are very important. This component is addressed very well in the current SWPPP.

Extended Detention (ED) Ponds

These facilities (often referred to as "dry" ponds) temporarily detain a portion of the runoff from each storm for a period of time. ED ponds provide excellent stormwater quantity control if adequately sized. These ponds utilize a fixed-size outlet orifice to control the outflow rate and are sized in accordance with design criteria. These ponds are typically designed to contain stormwater for 48–72 hours. ED ponds often have a sediment-settling forebay to enhance their effectiveness and increase their longevity (Figure 21). Typical ED ponds provide moderate removal of particulates (the median removal rate for TSS is 61%)

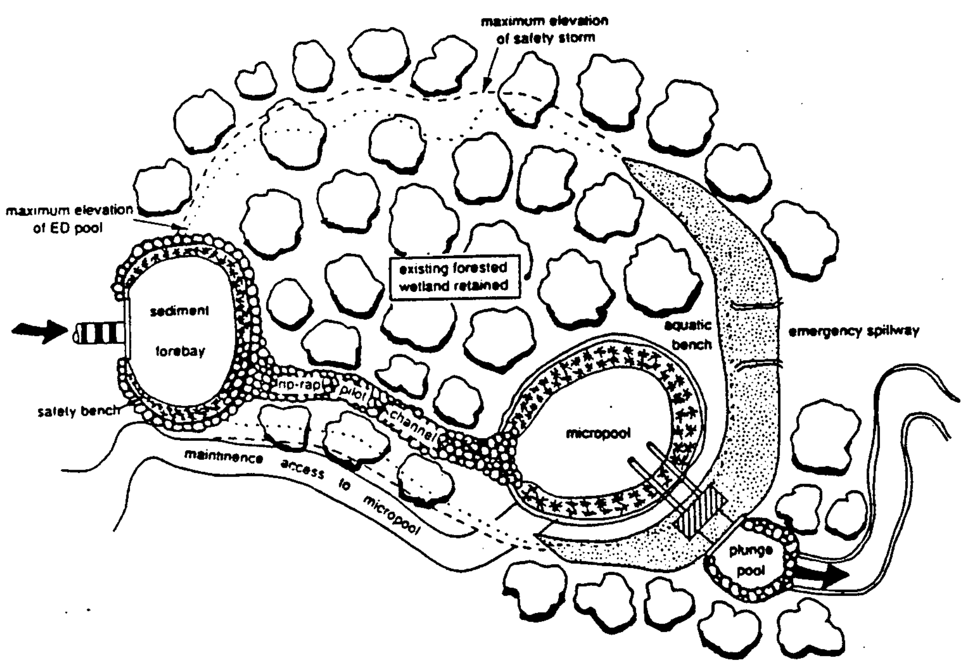


Figure 21. Enhanced extended detention (ED) dry pond.

but little removal of soluble pollutants. The primary pollutant-removal mechanism is settling of particulates. Construction costs are usually low, but long-term maintenance can be a burden. Depending on the sediment input, ED ponds are susceptible to clogging. If not properly maintained (periodically mowed and dredged), ED ponds can become eyesores or nuisances for nearby residents in addition to being ineffective. ED ponds can serve a secondary role as wildlife habitat if vegetation is properly maintained. Wetland features can be incorporated into these facilities.

Wet Ponds (WP) and ED Wet Ponds

These are the most common stormwater ponds and consist of a permanent pool or pools of water for treating incoming runoff. Pollutant-removal mechanisms include settling, plant uptake, and biological decomposition. These ponds can be enhanced by including a sediment-settling forebay (Figure 22). A conventional WP provides moderate to high removal of both particulate and soluble pollutants (the median removal rate for TSS is 77%). These ponds work best for larger developments (10 acres or more) and have a good overall long-term performance provided sediment is removed on a regular basis. A WP can require a large area and can have negative environmental effects (poor dry-season water quality, downstream warming, and groundwater contamination). The construction and maintenance costs of a WP facility are moderate. Wetland vegetation can be included in the WP design to enhance pollutant removal and habitat formation. A deep WP can be a hazard to local residents, and for this reason these facilities are normally fenced. An ED WP is similar to a conventional ED pond except that a permanent pool is incorporated into the design to provide less chance of sediment resuspension and outflow.

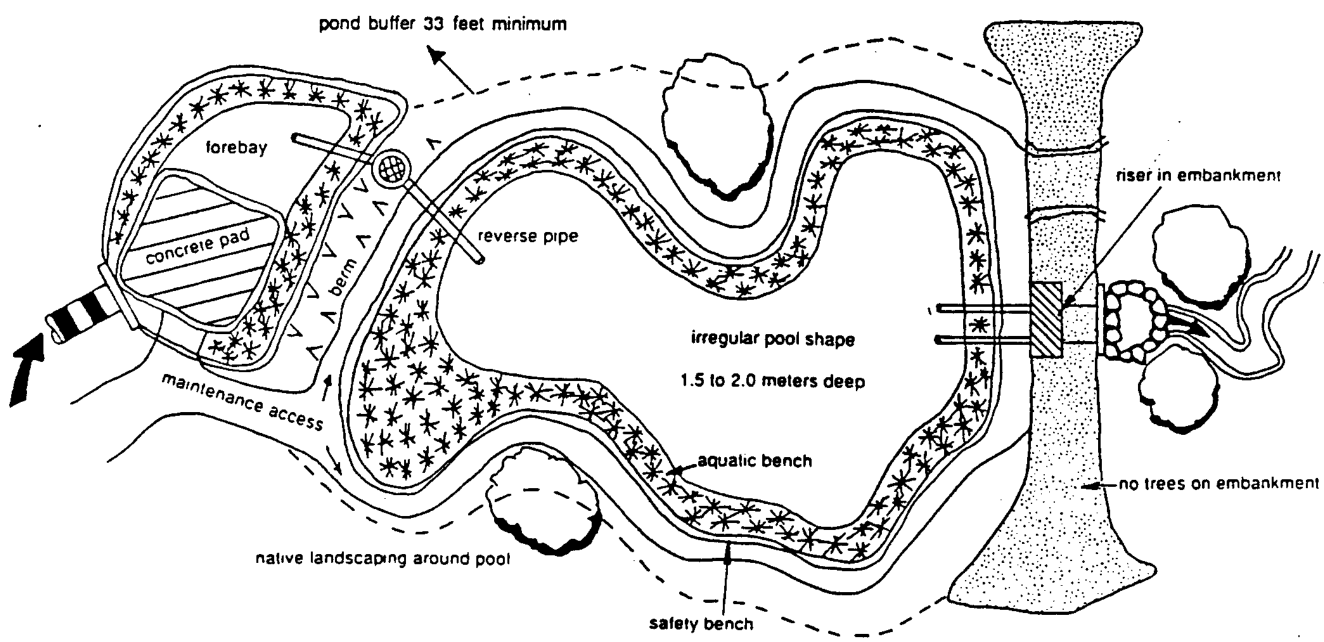


Figure 22. Enhanced wet pond.

Stormwater Wetlands

These are typically constructed systems and not located within delineated natural wetlands. Stormwater wetlands include a variety of forms, but typically consist of a combination of shallow pools and channels with wetland plants placed so as to provide filtering, uptake, and detention of stormwater. Stormwater wetlands are primarily used for treating water quality but can include some quantity-control features. Stormwater wetlands can be enhanced by the addition of a settling forebay, complex microtopography, and other landscaping methods (Figure 23). The features desired in most constructed wetlands include multiple bays or ponds, a torturous flow path between the inlet and the outlet, minimal open water, native wetland vegetation, and a water level that does not fluctuate. In general, stormwater wetlands have a high pollutant-removal capability (the median removal rate for TSS ranges from 60–80%, depending on the configuration and design).

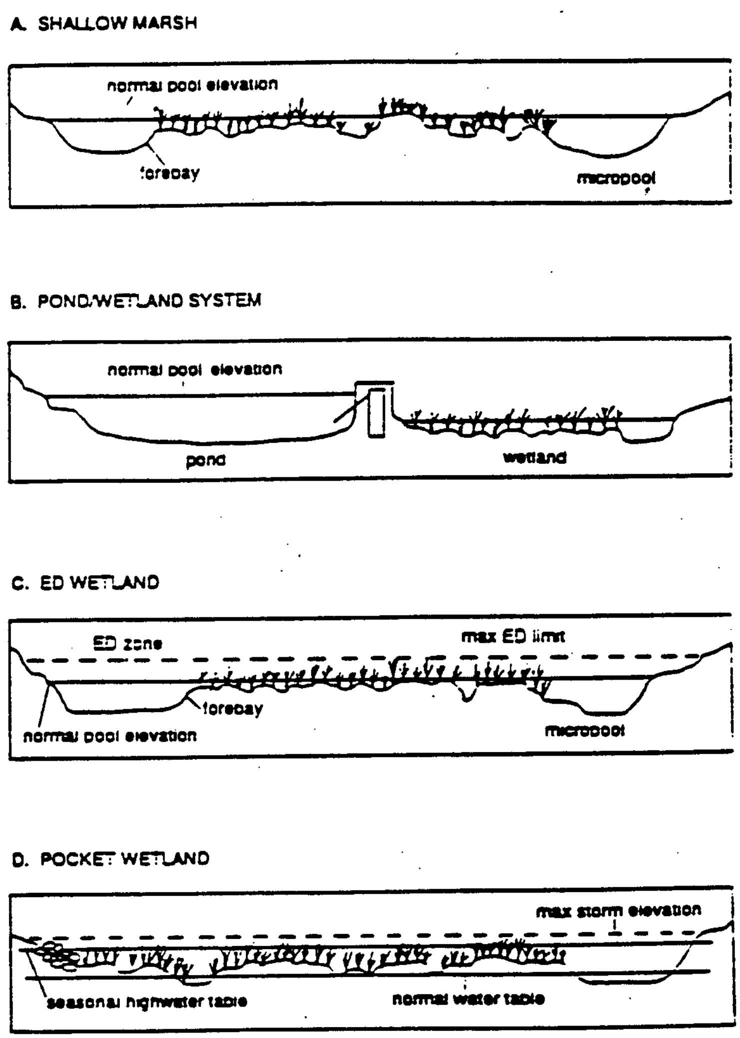


Figure 23. Types of wetlands constructed for stormwater treatment.

A combined pond/wetland system (Figure 24) can be very effective for both water quality treatment and quantity control. This "treatment-train" concept is becoming more common, in part because multiple treatment systems are more efficient at removing pollutants. Constructed wetlands may include design features that support natural wetland functions such as wildlife habitat. Construction and maintenance costs are comparable to those for conventional stormwater facilities. There are several types of stormwater (constructed) wetlands, including shallow marshes (Figure 25), pocket wetlands (Figure 26), and ED wetlands (Figure 27). Older stormwater basins can also be retrofitted with wetland features. Guidelines for selecting the type of constructed wetland to use for stormwater treatment are shown in Table 7.

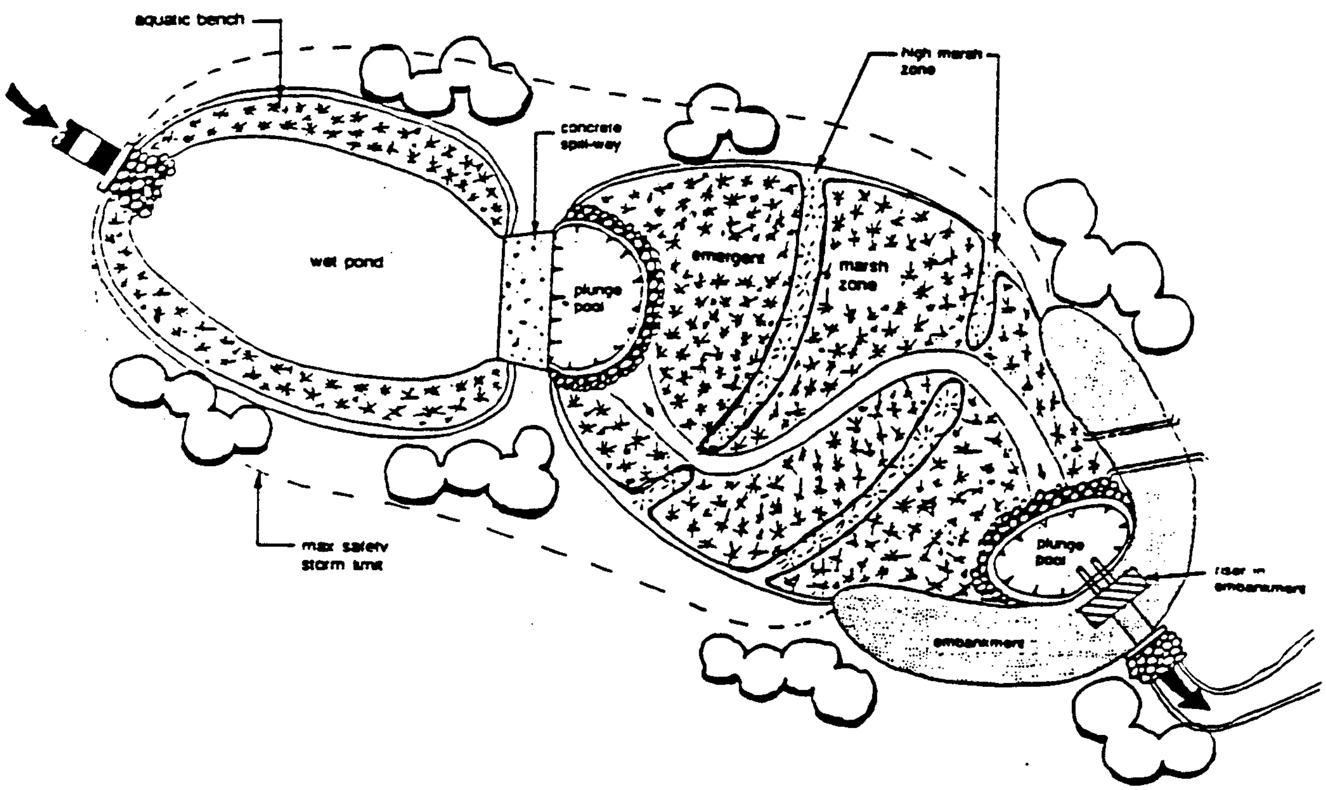


Figure 24. Combination pond and wetland system.

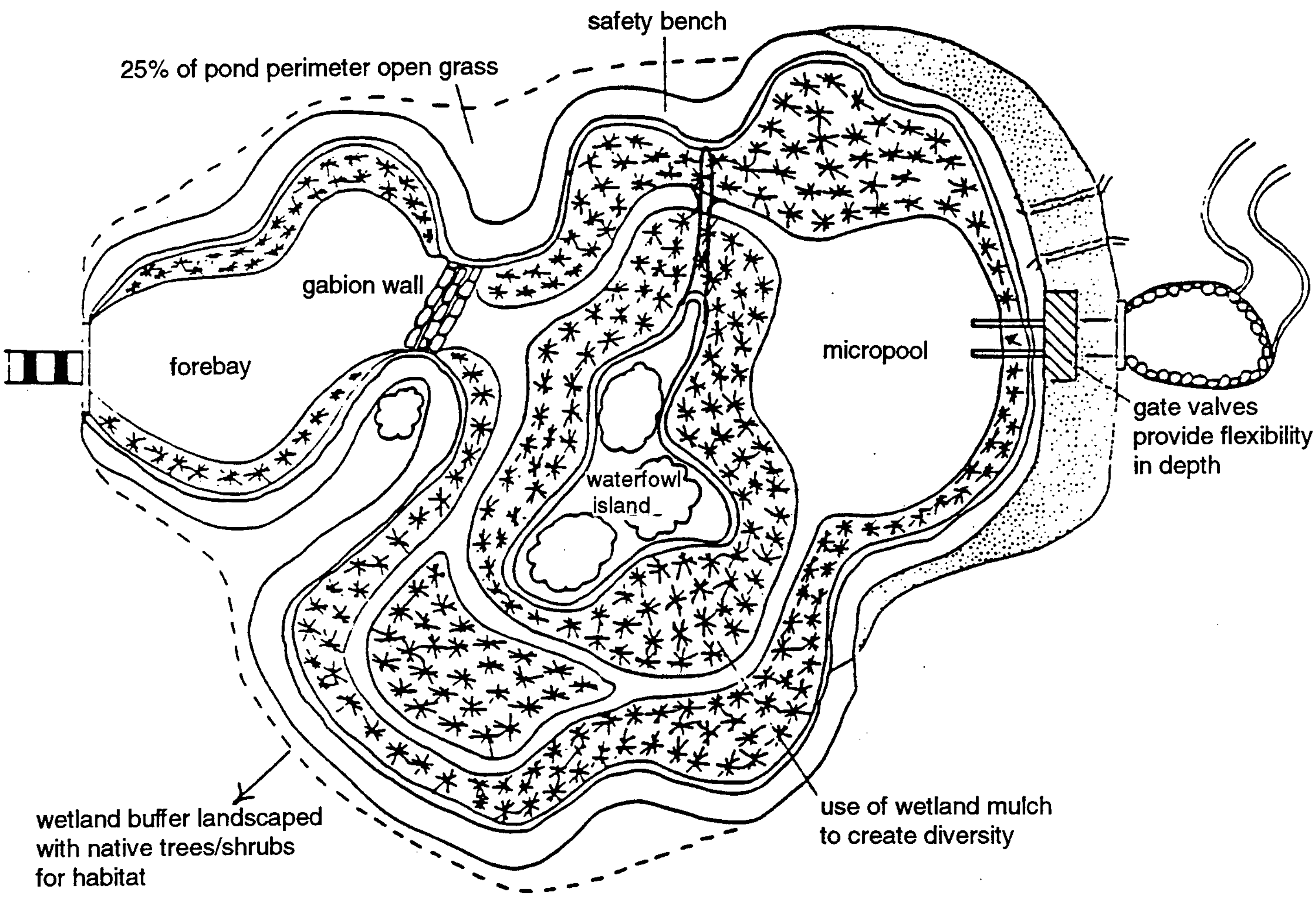


Figure 25. Shallow marsh wetland.

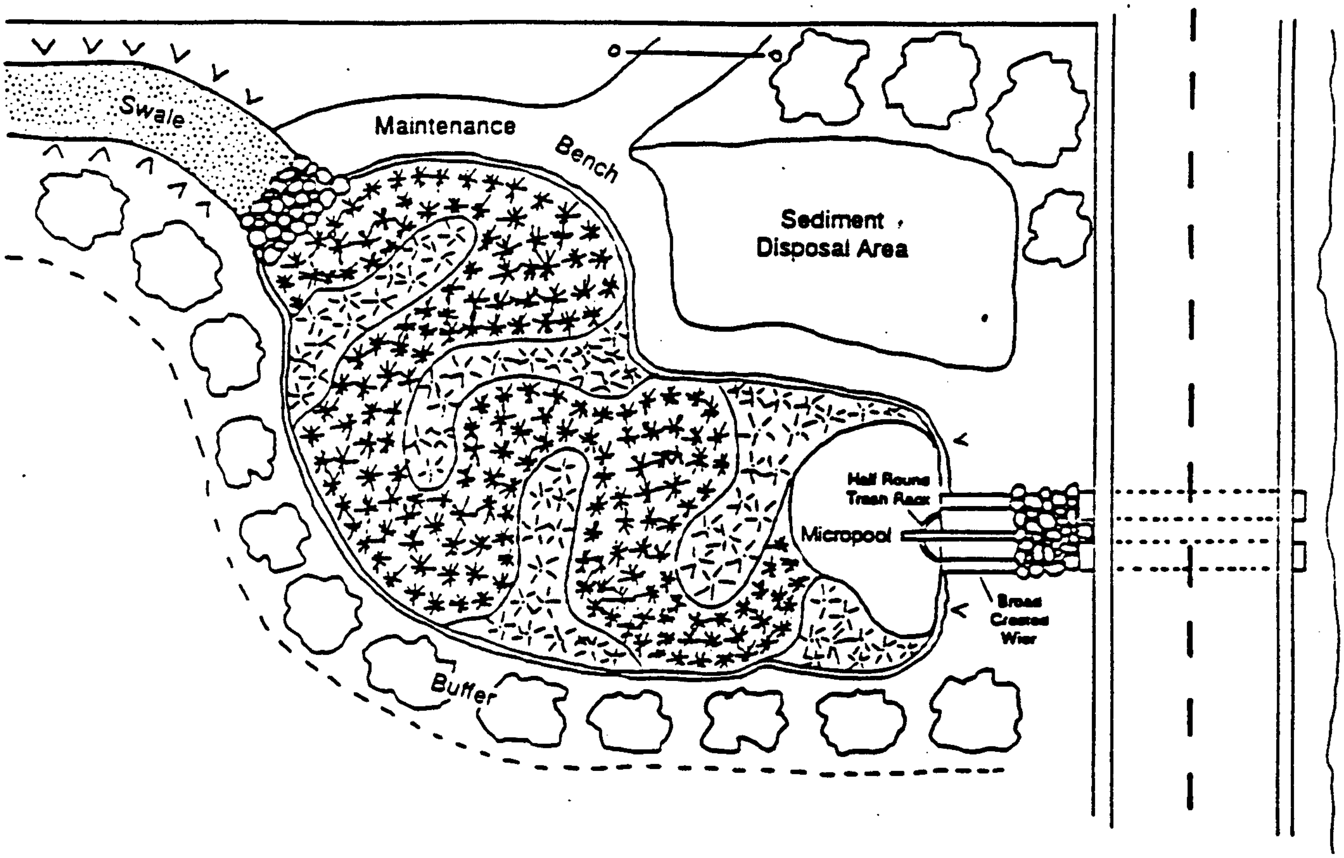


Figure 26. Pocket wetland.

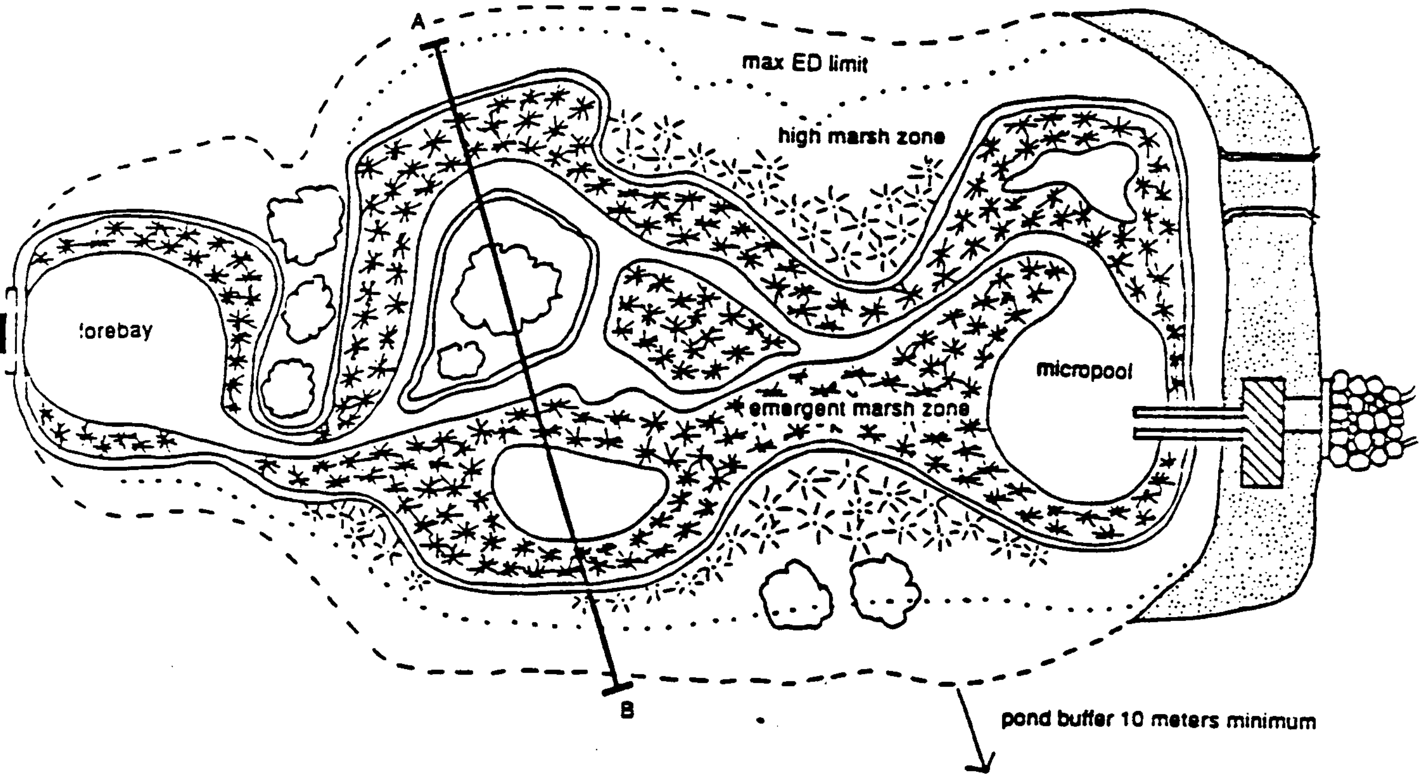


Figure 27. Extended detention (ED) wetland.

Table 7. Selection criteria for constructed stormwater wetlands.

Wetland Attribute	Shallow Marsh	Pond Wetland	ED Wetland	Pocket Wetland
Minimum Wetland/Watershed Area Ratio	2%	1%	1%	1%
Minimum Watershed Area (acres)	25	25	10	1
Dry Season Base Flow	Yes	Yes	No	No
Relative Potential for Ecological Benefit	High	High	Moderate	Low

Infiltration Systems

Infiltration systems are of three types—basins, trenches, and swales—and are designed for hydrogeologic conditions that support infiltration of all or most of the incoming stormwater runoff. Therefore they can be used only where the soil and underlying geologic conditions support infiltration. They are designed to store stormwater temporarily and gradually percolate it directly into the saturated soil zone. These systems are generally highly efficient at removing particulate pollutants but only moderately effective for soluble pollutants. Infiltration facilities are prone to sediment clogging even with regular maintenance.

An infiltration basin, or retention pond, is shown in Figure 28. Infiltration trenches (Figure 29) are small trenches that have been backfilled with gravel and sand. They are commonly used at the downslope edge of parking lots or other impervious surface areas. Infiltration swales (Figure 30) can also be constructed as part of an in-line stormwater treatment system. Few data are available on the performance or longevity of infiltration basins or trenches. These facilities are generally more costly to construct and maintain than conventional stormwater detention facilities.

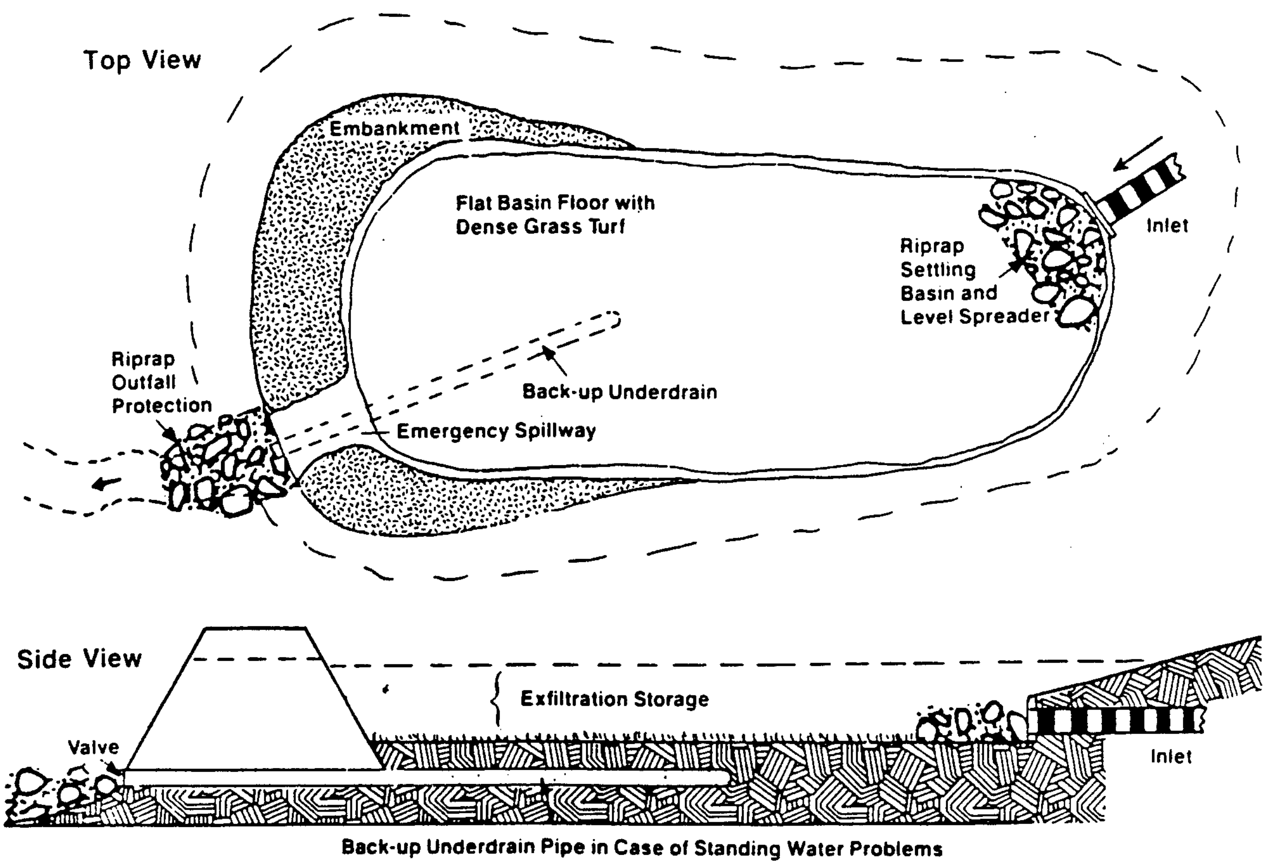


Figure 28. Infiltration basin.

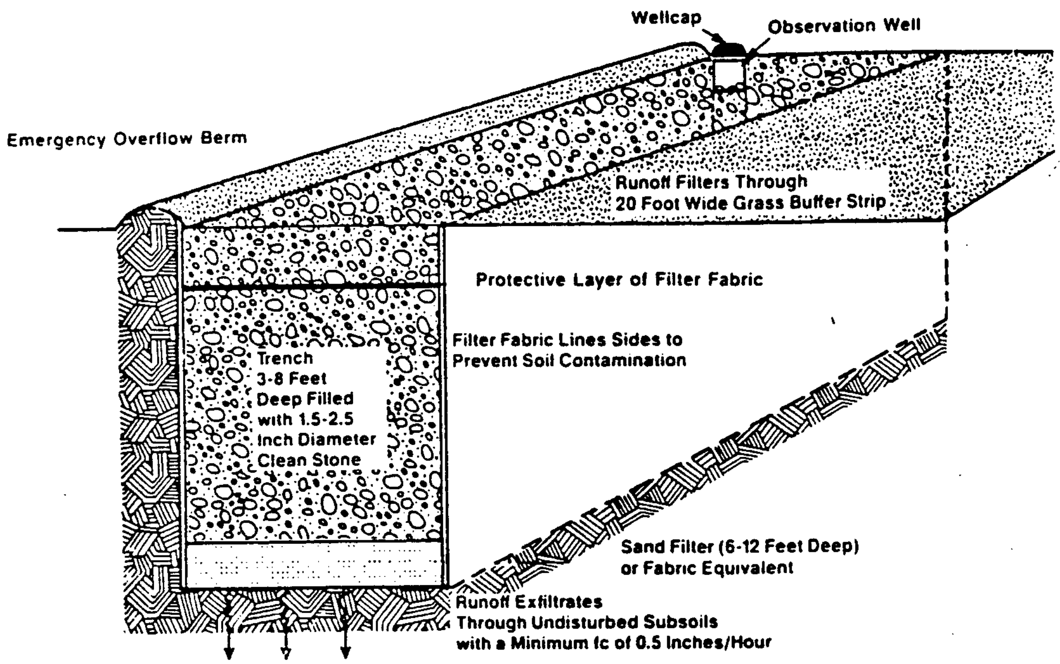


Figure 29. Infiltration trench.

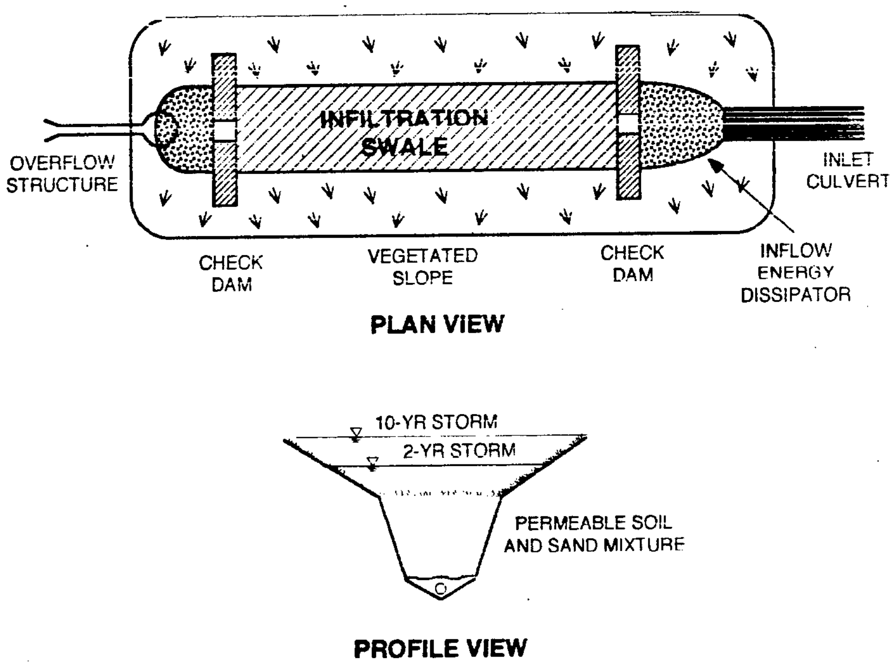


Figure 30. Infiltration swale.

Biofiltration Swales and Filter Strips

Biofiltration swales are vegetated channels designed to filter incoming stormwater which is directed into them as sheet flow. Check dams are often utilized to increase stormwater detention and enhance swale effectiveness. Biofiltration swales can be designed as dry or wet systems, depending on the hydrogeologic conditions and site requirements. Figure 31 shows a dry biofiltration swale, and Figure 32 a wet swale. Filter strips (Figure 33) are designed to be dry systems except during storms. Filter strips are vegetated sections of land designed to accept runoff as sheet flow. Grasses and wetland vegetation are appropriate for all these facilities. Such facilities can be quite effective in removing stormwater pollutants from small, nonindustrial areas (the median removal rate for TSS is 81%) and have been shown to work best in residential areas. Filter strips can be incorporated into riparian buffers along streams or wetlands and can serve as a transition from lawns to riparian forest zones (they should not be considered a replacement for riparian buffers). Construction and maintenance costs are relatively low.

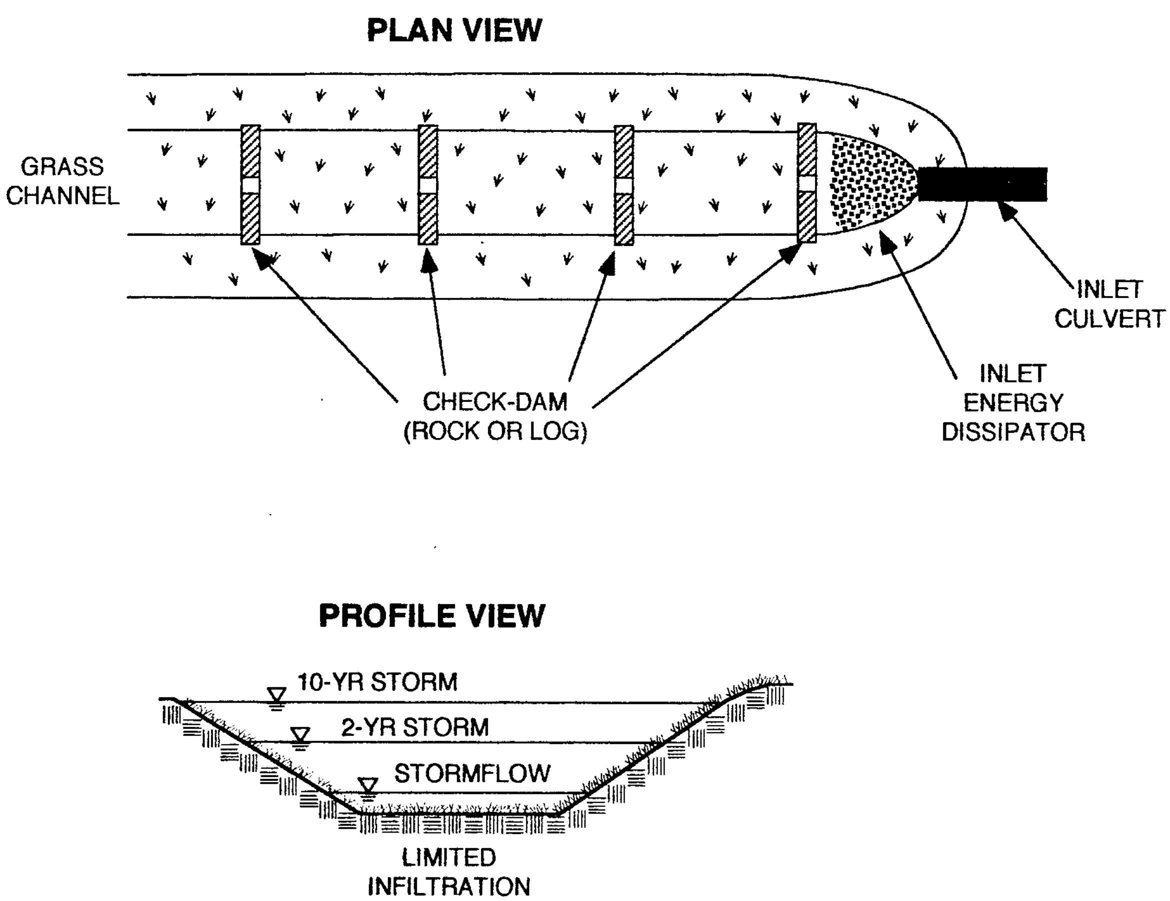


Figure 31. Biofiltration swale.

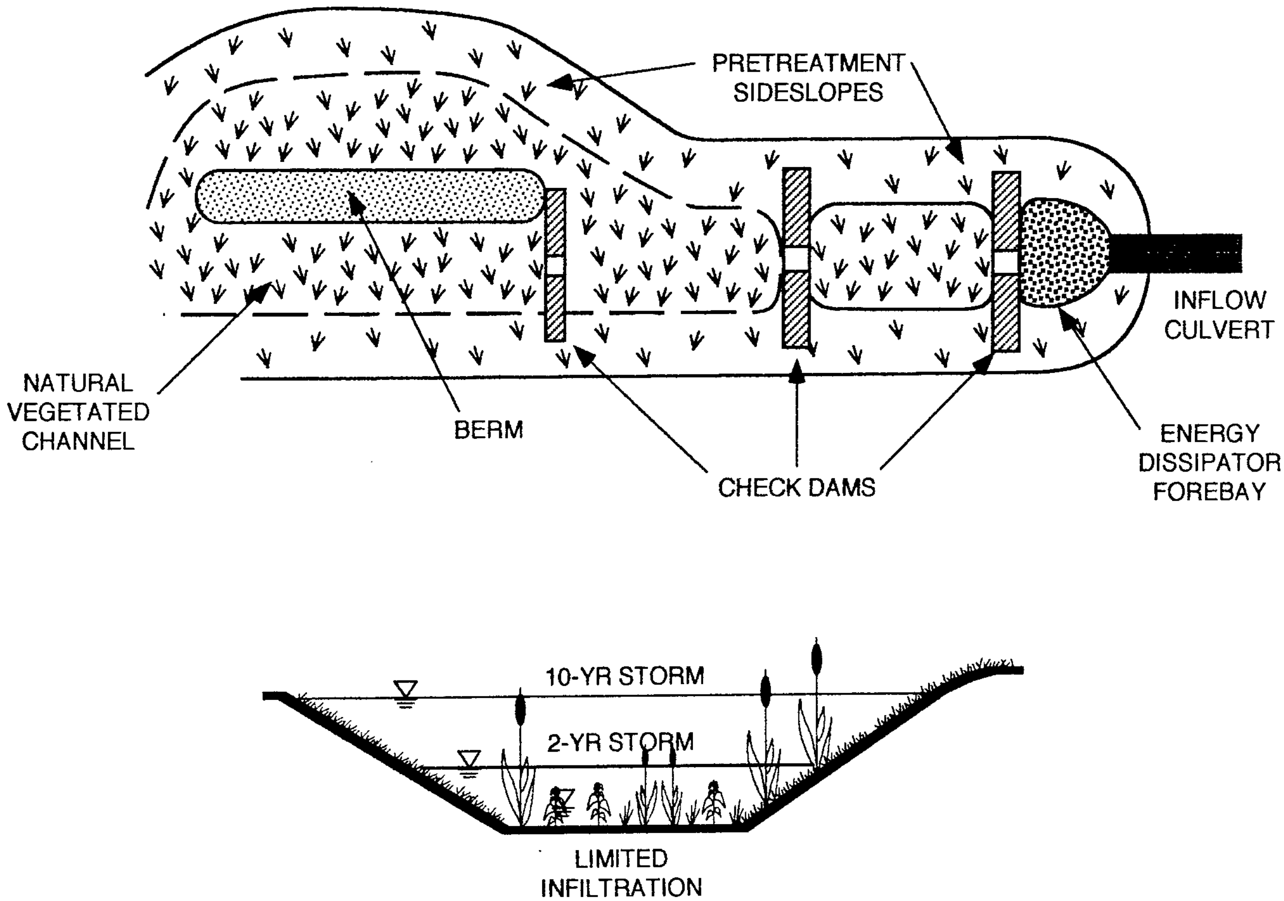


Figure 32. Biofiltration (wet) swale.

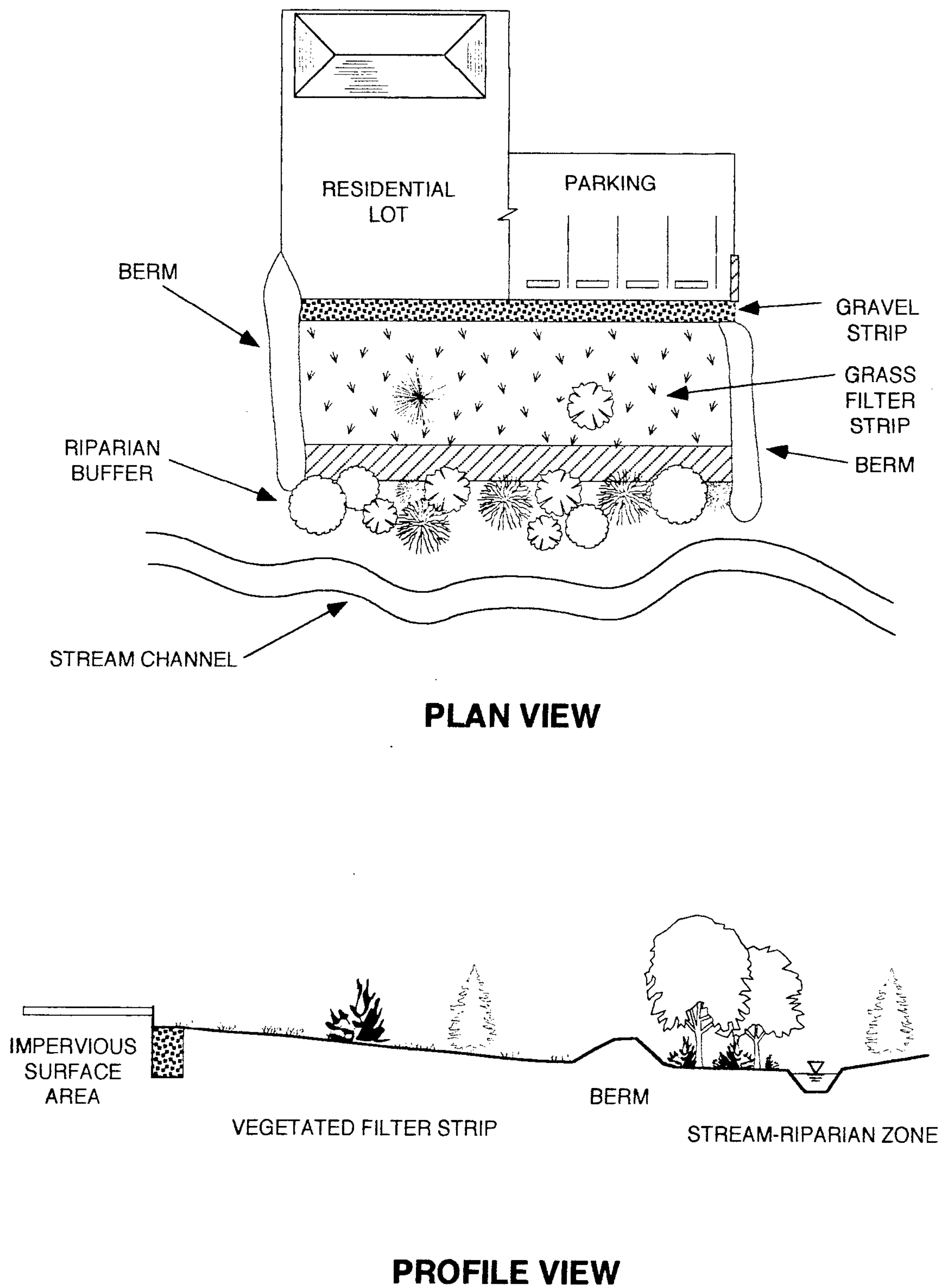


Figure 33. Filter strip.

Biodetention

This is a new technique developed as a cost-effective alternative to detention ponds that is applicable to sloped sites (Murfee et al., 1997). This innovative method capitalizes on the proven effectiveness of several conventional BMPs. Biodetention utilizes multiple treatment mechanisms, including screening of larger particulates, vegetative filtering of smaller particulates, sedimentation, and infiltration. Figure 34 shows a typical biodetention system. A rock berm at the head of the facility screens coarse particulates and debris. This berm also serves to disperse the channelized inflow into a more dispersed sheet flow. The stormwater then flows downslope through several alternating vegetated filter strips and vegetative barriers. The filter strips remove pollutants by sedimentation, filtration, uptake, and microbial degradation. The vegetative barriers are narrow strips of coarse perennial vegetation established along the contour of the slope to detain stormwater and maintain sheet flow as the runoff flows downslope. As a BMP system, biodetention has been used in only a few cases; the components are proven techniques.

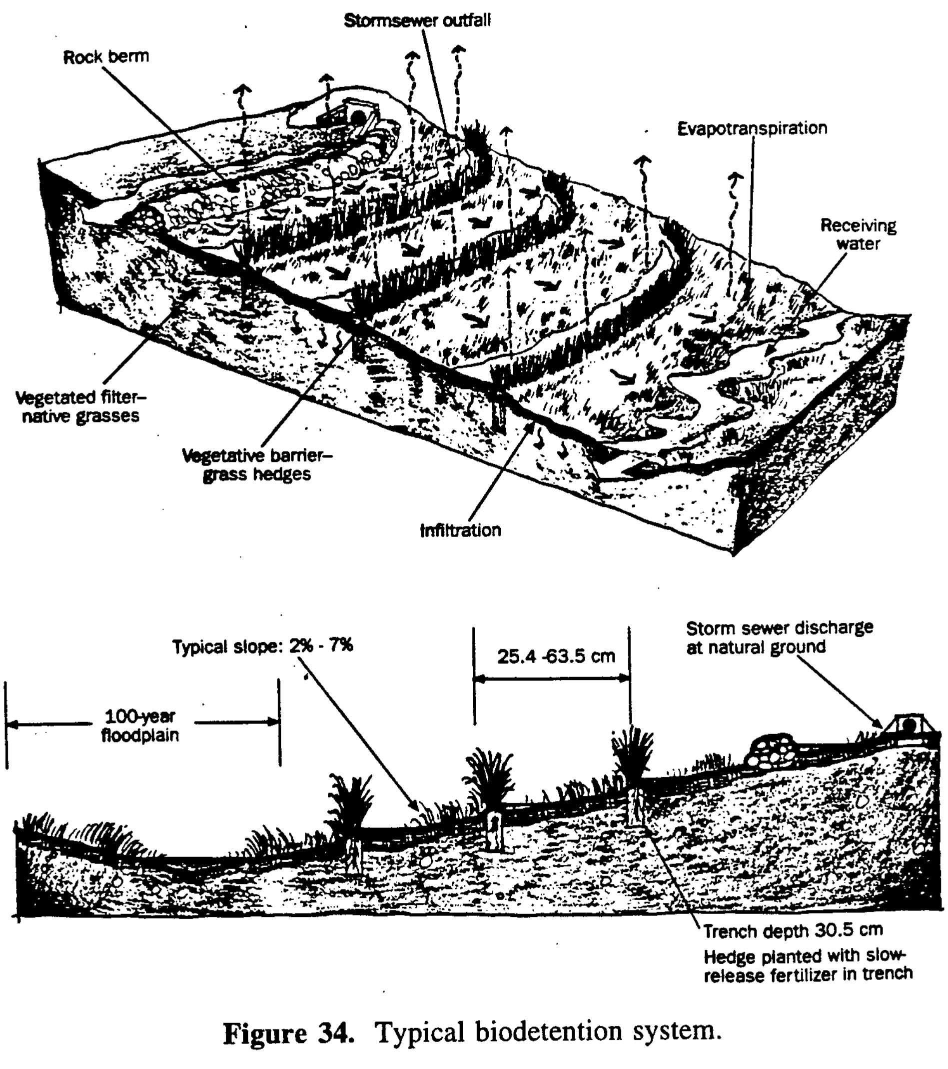


Figure 34. Typical biodetention system.

Bioretention

Bioretention systems are functionally similar to biodetention and infiltration facilities but are designed to hold a volume of stormwater for an intermittent period of time. These facilities are appropriate only where standing water is not a problem. Figure 35 shows a bioretention area also used for treatment of impervious surface runoff. Figure 36 shows a typical bioretention filter such as would be used to service a parking lot.

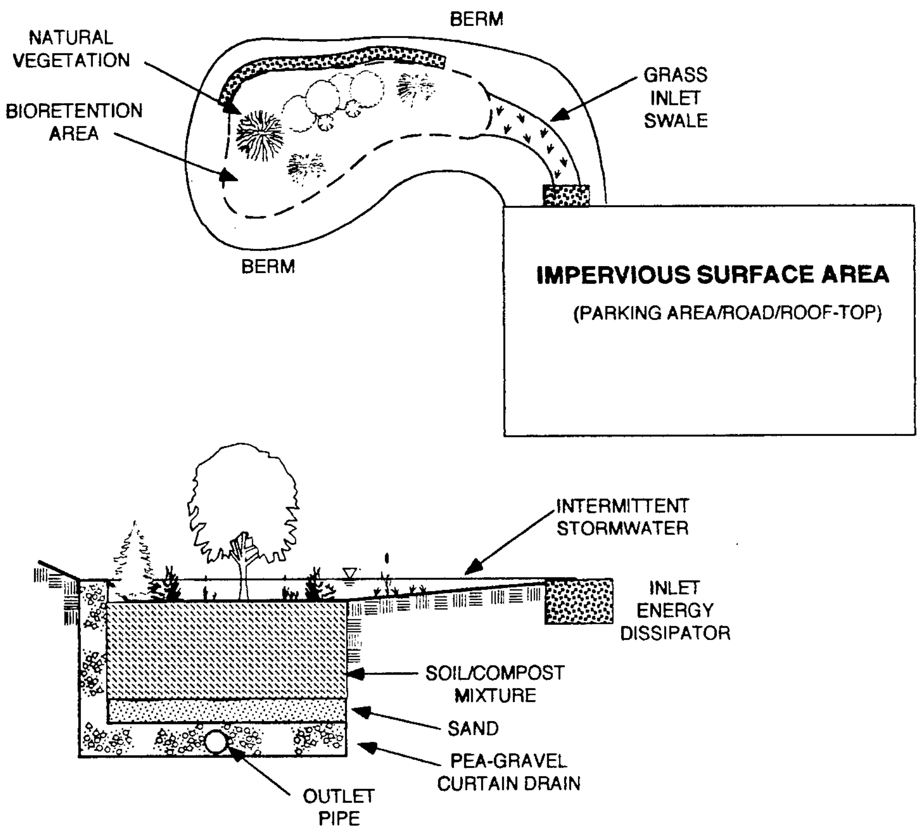


Figure 35. Bioretention area.

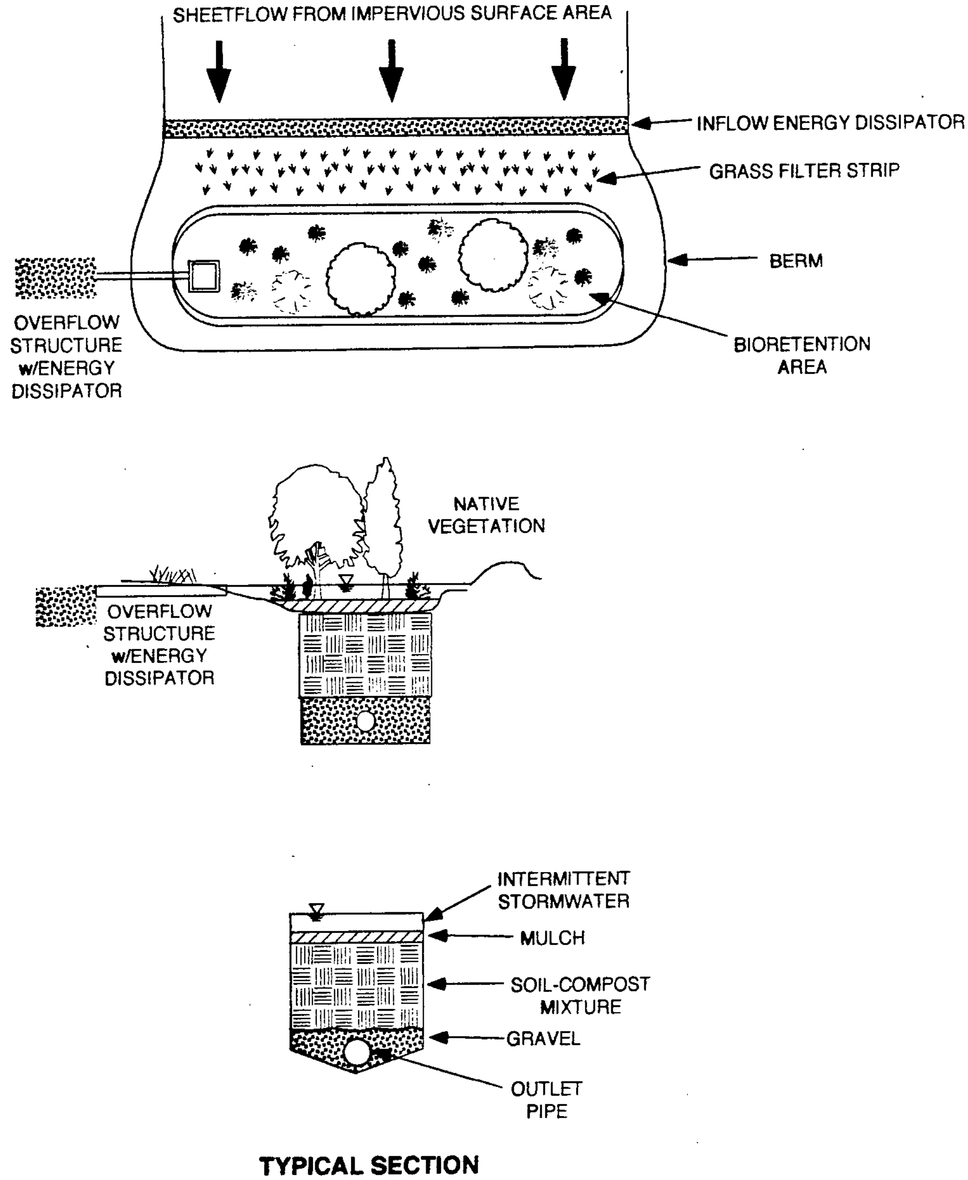
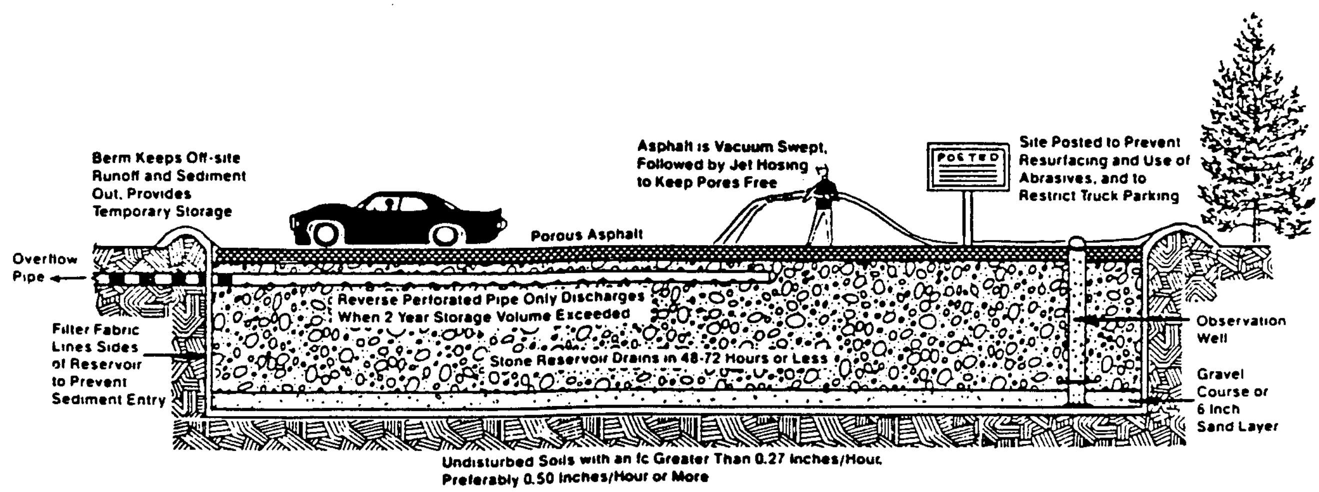


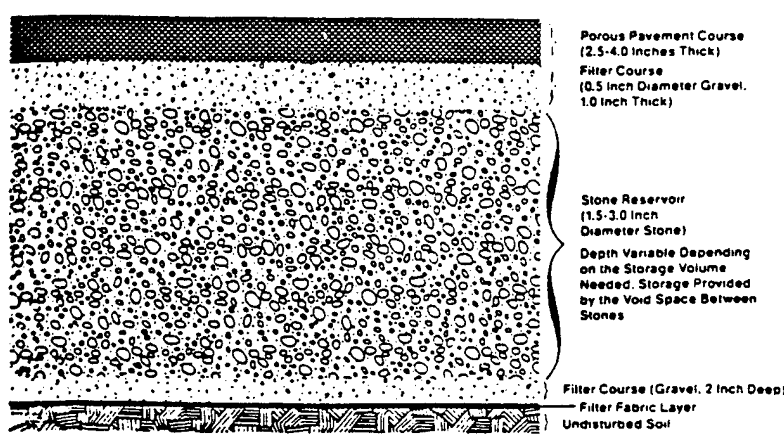
Figure 36. Bioretention filter.

Porous Pavement

Porous pavement (PP) is an alternative to conventional pavement as a method of infiltrating stormwater and reducing impervious surface runoff. Typically, some type of porous asphalt or paver is utilized as the top surface over an excavated, underground gravel reservoir (Figure 37). Few performance or longevity data are available on these treatment systems, but PP systems have been shown to be effective in removing particulate and soluble pollutants. Many of the early porous pavement systems failed because of sediment clogging or for aesthetics reasons. The UW Center for Urban Water Resources is currently testing several variants of this system for use in parking areas or light-duty access roads. Construction costs for PP systems are higher than those for conventional pavement but can be offset by the savings in not having to build supporting treatment facilities.



Side View



Source: Schueler, 1987

Figure 37. Porous pavement.

Sand Filters

Sand filters are a relatively new and still fairly uncommon stormwater BMP facility. In these systems, stormwater is diverted into a basin with a bed of sand and an underground (perforated) piping network (Figure 38). Runoff is gravity filtered through the sand bed and collected in the pipes for distribution in the stormwater conveyance system. Enhanced sand filters may incorporate a layer of peat over the sand and/or a vegetated surface layer. Sand filters are highly effective at removing particulates (the median removal rate for TSS is 83%) but only moderately effective on soluble pollutants. The construction costs are a bit higher for sand filters than for conventional BMP facilities, and the maintenance costs are comparable. Sand filters do not appear to be prone to sediment clogging. These facilities are useful in watersheds where groundwater contamination is of concern. Small sand filters can also be employed to treat pollutant hot spots.

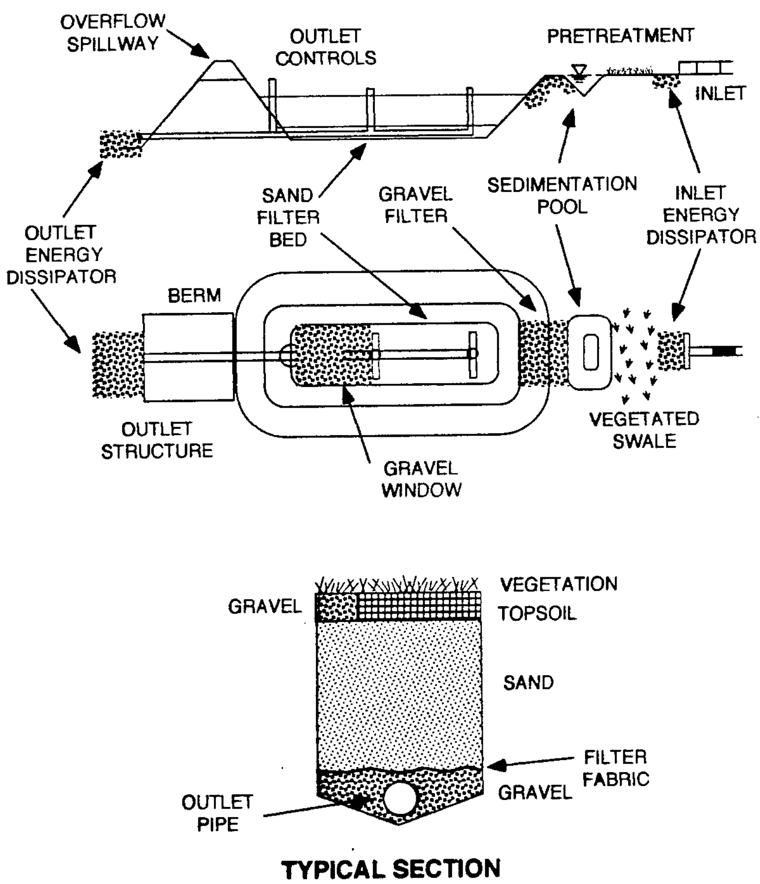


Figure 38. Sand filter system.

On-Site Stormwater Treatment Systems

These systems include a variety of innovative technologies. Most are relatively small, self-contained systems that are designed to treat small areas of impervious surface (one or two acres). These systems are well suited for treating so-called stormwater "hot spots," such as vehicle maintenance areas, that have a high potential as sources of pollutants.

Submerged Gravel Filters

The simplest and most common of these on-site stormwater treatment systems is the submerged gravel filter (Figure 39). This system uses a combination of mechanical filtration, microbial activity, and biological uptake to treat stormwater.

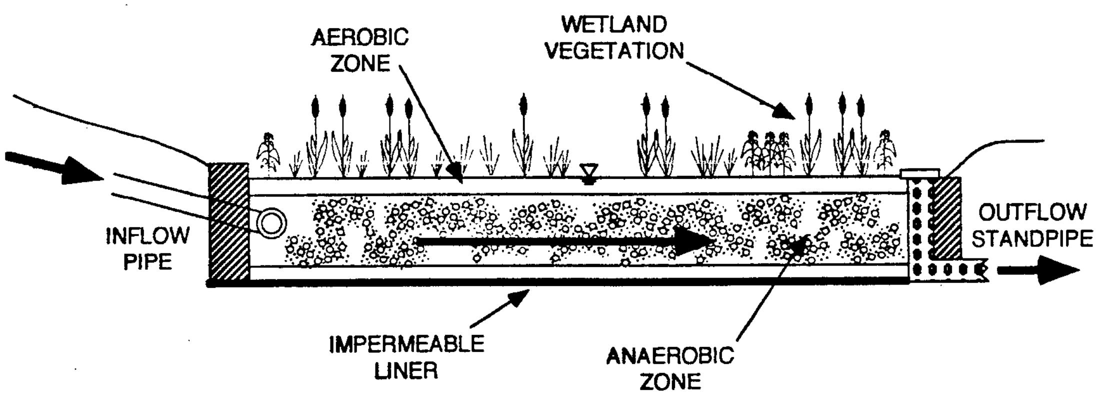


Figure 39. Submerged gravel filter.

Compost Media Filters

Compost media filters are also excellent on-site stormwater treatment systems. The CSF® system designed and built by Stormwater Management of Portland, Oregon, is the state-of-the art product. It uses a pelletized, deciduous leaf compost to filter out petroleum products, metals, sediment, nutrients, and other pollutants. The compost is put into radial-flow cartridges which are inserted into precast concrete vaults or custom designed structures that are installed on site. Various drop-in and above-ground configurations have been built (Figure 40). Primary treatment is accomplished by a combination of adsorption, mechanical filtration, and ion exchange. The CSF design has been demonstrated to remove up to 90% of particulates, 85% of oils and greases, and 98% of metals. The CSF system typically utilizes about 10% of the space required for conventional stormwater treatment facilities, making it ideal when space is limited. The cost of the CSF design is also very competitive (approximately $1000 per cartridge, which treats 15 gal/min of runoff).

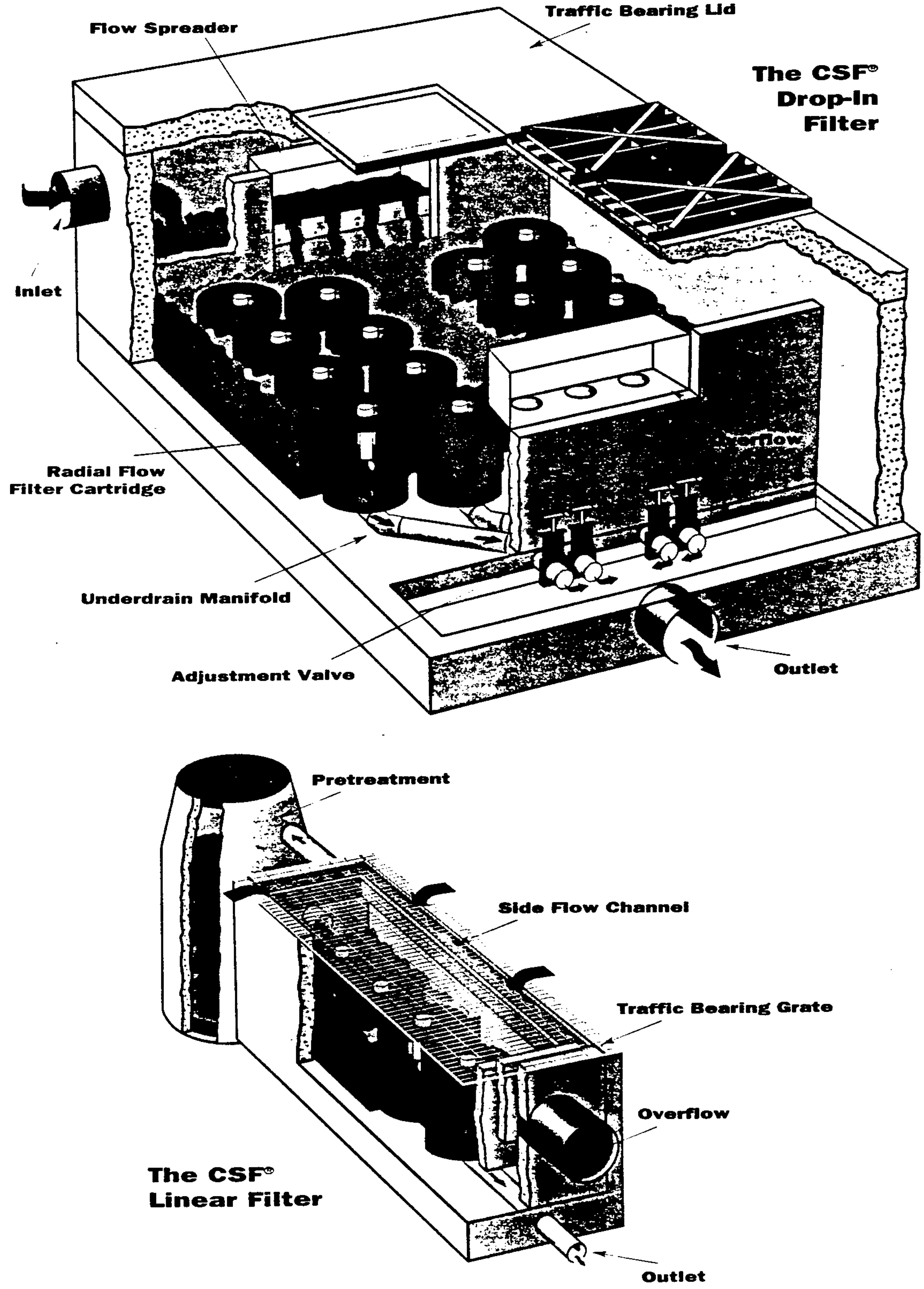


Figure 40. CSF® compost filter media (Stormwater Management, Inc.)

Modular Wetland Systems

Modular wetland systems utilize the same principles as conventional treatment wetlands but are much more compact. The StormTreat System™ (STS), also commercially available, is the best example of this type of on-site treatment technology. The STS consists of a series of sedimentation chambers and a miniature, constructed wetland and is contained within a modular (3-m diameter) polyethylene tank (Figure 41). These systems are compact, easy to maintain, and cost about $5000 per unit (one to four tanks are typically required to treat one acre of impervious surface). The STS utilizes a combination of sedimentation, mechanical filtration, and biochemical processes to treat incoming stormwater. Pollutant removal rates are 94% for total coliform bacteria, 95% for TSS, 90% for zinc, 89% for total phosphorus, and 90% for total petroleum hydrocarbons.

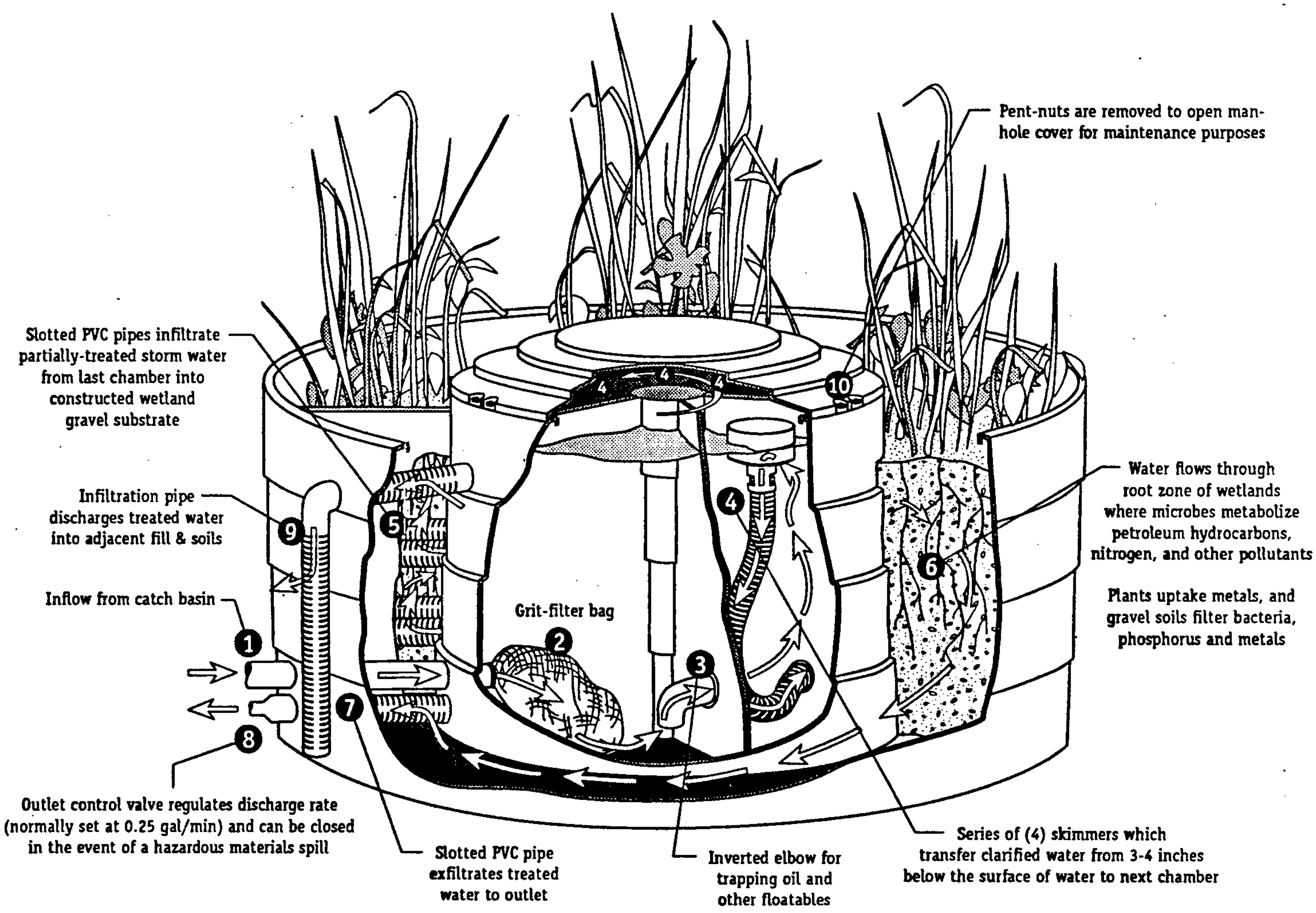


Figure 41. StormTreat System™ (STS).

Vorticity Chambers

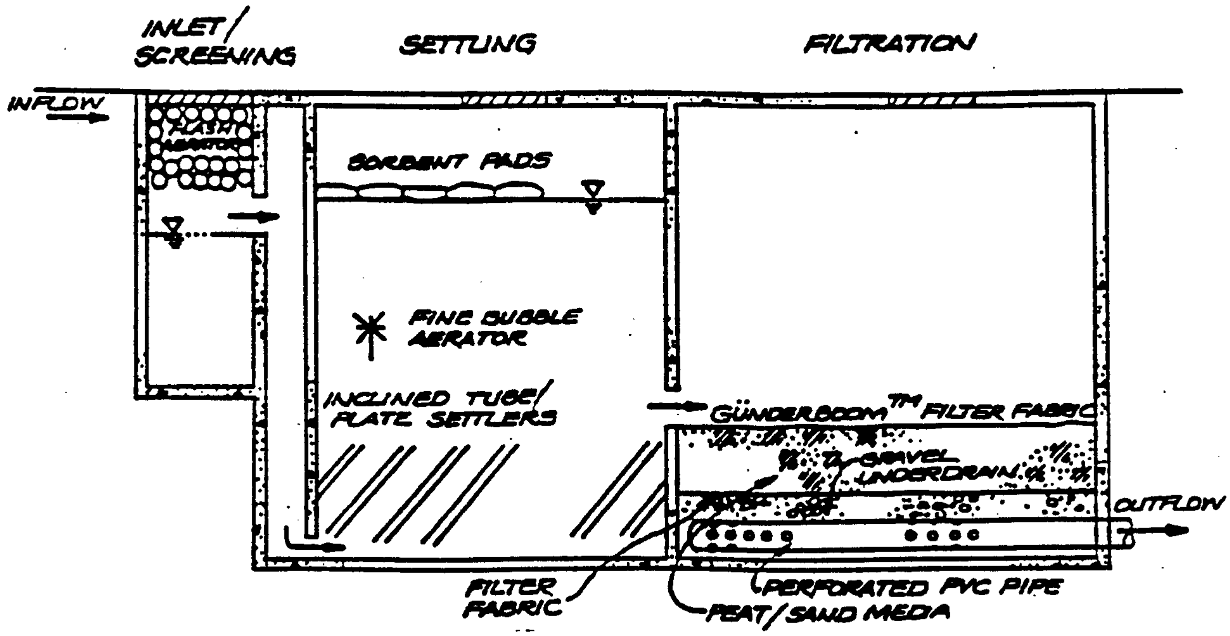
The Vortechs stormwater treatment system (built by Vortechnics of Portland, Maine) is another commercially available on-site treatment system. This system is also designed for minimal use of space and high pollutant (particulates, petroleum hydrocarbons, and metals) removal (80% for TSS). This system uses a unique swirling-flow grit chamber to settle out sediment and an oil trap to remove floatables.

Multichamber Treatment Train (MCTT)

The MCTT is designed to treat stormwater runoff from paved, urban "hot spots" such as automotive service and repair stations. Such hot spots can contain pollutant concentrations up to two orders of magnitude greater than those found in other urban areas. The higher potential for heavy stormwater pollutant loading becomes apparent when one also considers the numerous hot spots located in most urbanized areas. This being the case, it becomes prudent to treat runoff close to the source to minimize volume and mixing with less polluted runoff. That is the objective of the MCTT. Effective, on-site treatment of stormwater hot spots has been a problem for a number of reasons. First, most hot spots tend to be small in size and lack adequate space for installing conventional treatment systems. Second, the use of gravitational settling as the primary pollutant-removal mechanism has not worked well for the types of pollutants generated at hot spots. Third, infiltration is typically not a viable option. Last, the conventional oil/water separators have not been effective (Schueler, 1994). The MCTT is a new, innovative system which has had only limited testing but has worked well so far (Pitt, 1995). In pilot studies, the median removal rate was 85–98% for TSS, 90–93% for total zinc, and 80–84% for total phosphorus. Relative toxicity was also reduced by >95%. MCTTs utilize a series of components to treat concentrated, transportation-related stormwater pollutants (Figure 42). The typical MCTT consists of an inlet/screening chamber, a settling chamber, and a filtration chamber. The inlet chamber consists of a conventional catch-basin sump that traps and settles the largest particulates and a flash-aerator that removes volatile pollutants. The settling chamber consists of a large basin equipped with inclined tubes or plates to increase the surface area for sediment settling, an electric bubble aerator, and a set of floating sorbant pads to trap oils. The filtration chamber consists of a filter system composed of a filter fabric, a peat and sand filter (to remove small particulates and dissolved particles and provide ion exchange), and a gravel/pipe drain (see Figure 42). It is designed for underground installation and can be sized to contain various amounts of runoff (typical size requirements are 0.5–1.5% of the area of impervious drainage surface). Construction and maintenance costs appear moderate.

Oil/Water Separators

Conventional oil/water separators are commercially manufactured devices designed to remove heavy particulates and hydrocarbon pollutants. The coalescing-plate design is probably the most commonly used. These systems have a limited capability to remove stormwater pollutants and appear to be effective only for large particulates and adsorbed hydrocarbon compounds. They can be overwhelmed by large storms. Maintenance requirements and costs can be quite high, depending on the installation situation.



The multi-chamber treatment train (MCTT) consists of three treatment units in sequence—an inlet screening chamber, a sedimentation chamber and a filtration chamber. Most of the high pollutant removal occurs in the last two chambers.

Figure 42. Multichamber Treatment Train (MCTT).

Drain Inlet Cleaning and Retrofitting

This is an excellent example of a preventative BMP facility. Inspection and removal of large debris from stormwater inlets should be performed on a regular basis (at least monthly and possibly weekly during the storm season). Stenciling of storm drains has also been demonstrated to raise public awareness. More thorough storm-drain cleaning should be done at least annually prior to the start of the winter rains. Vacuum extraction appears to be the most efficient method of cleaning, although manual methods also work. Installation of commercially available, "drop-in" retrofit filters or locally manufactured retrofit filters (Figure 43) in selected catch basins should be considered. Areas where heavy automobile traffic can be expected to produce higher levels of particulate pollutants, metals (zinc and lead), and petroleum hydrocarbons are good candidates for these filter inserts.

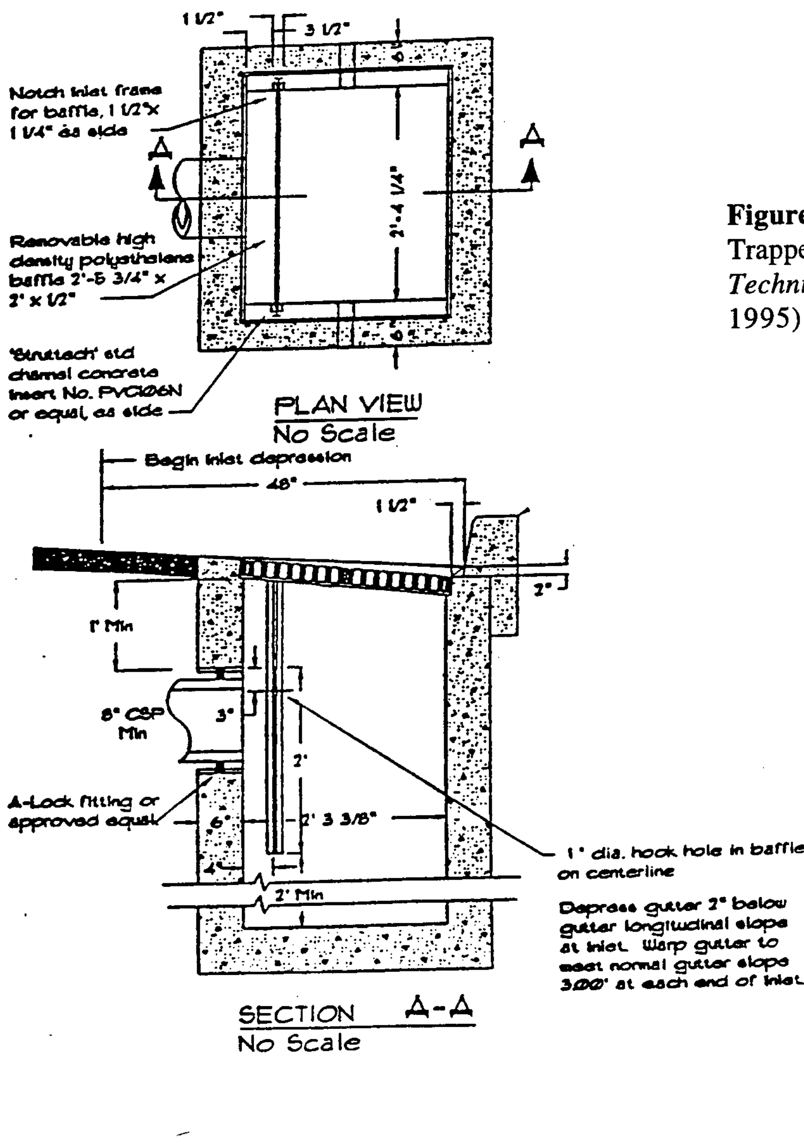


Figure 43.
Trapped catch basin (*Portland Technical Guidance Handbook*, 1995).

Street Sweeping

Recent studies have found that street-sweeping programs can significantly reduce pollutant washoff from impervious surfaces in urban watersheds (Sutherland and Jelen, 1996). These studies indicate that reductions of up to 80% in annual total suspended solids (TSS) and associated particulate washoff can be achieved by bimonthly or weekly sweeping using the newest sweeper technology. A vacuum-assisted dry sweeper like that made by Enviro-Whirl Technologies, Inc., appears to be the most effective in picking up and containing fine sediment. These sweepers can also produce a marked improvement in local air quality by preventing resuspension of particulates (Port of Seattle, 1997). Older, broom-type sweepers do not appear to be effective. The frequency of sweeping and the resultant reduction in pollutant washoff will depend on precipitation patterns, watershed land use, sediment accumulation, and other environmental factors, but it is clear that street sweeping can achieve meaningful runoff quality benefits in most areas.

Riparian Buffers

The use of natural, vegetated riparian buffers to protect streams, lakes, and wetlands from the impact of human activities is fairly widespread. This is a common BMP in watersheds where the dominant land use is agriculture or where forest practices are prevalent. Most urbanizing areas also have some buffer requirements to protect surface waters from stormwater runoff. If these buffers are wide (>30 m), continuous (<2 breaks/kilometer), and consist of mostly mature forest, indications are that they will be very effective in mitigating the cumulative adverse effects of development activity (May, 1996).

RECOMMENDATIONS

Individual stream-rehabilitation and stormwater-mitigation projects are described in detail in Appendix A. These projects are prioritized based on their importance with regard to the protection of aquatic resources as well as the prevention of damage to property. Each project includes a detailed description of work as well as an estimate of the manpower, equipment, and materials needed to complete the project. In addition, most contain a diagram of the proposed project. The objectives of future surface and stormwater management programs are outlined below.

Watershed Management

- Owing to its currently undeveloped condition, the *Cattail Creek* subbasin should be designated as a resource conservation area. Development within this catchment should be excluded or severely limited. *The watershed should be managed for resource protection*, with only low levels of recreational activity allowed. Selective timber harvest in the upland sections of the catchment may be allowed but only if it is greater than 30 m (100 ft) from the stream channel, wetland areas, and steep slopes. Because the headwaters of this stream are located off base, a close coordination with Kitsap County will be required to protect the downstream portions of the creek. For example, the base could provide land for construction of a regional stormwater-treatment facility if development is planned for the headwaters.
- *The watershed management goal for Devils Hole Creek should be to halt further degradation of stream quality and to enhance ecological integrity where possible.* This will require some extensive construction of stormwater-treatment facilities, rehabilitation of in-stream habitat, and replacement of multiple culverts if the creek is to be restored to its full potential to support native salmonids.
- Because the headwaters of *Clear Creek* are located within the boundaries of NSB-Bangor, the primary objective should be to protect downstream portions of the stream system from stormwater runoff from the base. NSB-Bangor has so far met this objective. The Trident Lakes and PW stormwater-treatment ponds are operating as designed. Additional stormwater treatment should be considered for portions of the upper base that drain into the north branch of Clear Creek.

Stormwater Management

- Stormwater-treatment facilities should be constructed to service the West Family Housing area as indicated in the detailed project descriptions. Two regional-scale BMP facilities are recommended for this area.
- A regional stormwater BMP facility (constructed wetland) should be built to service that portion of the upper base not currently served by the PW retention pond. This area drains off base into Clear Creek.

- A stormwater-treatment facility (constructed wetland) should be built near TRF. This system would be designed to improve water quality in Devils Hole Creek and protect sensitive in-stream salmonid habitat.
- Consideration should be given to utilizing a few of the more innovative stormwater-treatment BMPs to service NPS pollutant "hot spots" and transportation-related impervious areas.

Aquatic Resources Management

- A fish passage should be constructed at the outlet of Cattail Lake, and a hatchery-based restocking program should be instituted for native cutthroat trout as well as for coho and chum salmon. This effort should be a cooperative program with local tribal and state fishery agencies.
- Tribal and state fisheries agencies should be consulted on how best to improve coho and chum salmon runs in Devils Hole Creek.
- Riparian buffer zones should be established around all streams within the base. These buffers should be marked to prevent encroachment and should be actively managed for mature, native (coniferous) forests. Buffers of 100 m are recommended, with a 30-m buffer established as the minimum allowable.
- High priority should be given to replacing those culverts identified as current or future barriers to salmonid migration. The culverts should be replaced by bridges or so-called arched culverts with natural streambed bottoms.
- A long-term program of in-stream habitat enhancement and rehabilitation should be instituted for all three stream basins under the influence of NSB-Bangor. This program would include habitat-improvement projects identified for on-base portions of each creek and cooperation with Kitsap County on portions of Clear Creek that are outside NSB-Bangor jurisdiction but are affected by base activities.

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APPENDIX A

Project Descriptions: Stormwater Management Enhancement and In-Stream Habitat Rehabilitation, US Naval Submarine Base, Bangor, Washington

NSB-BANGOR SWM PROJECT SUMMARY

Project Location:	All NSB-Bangor streams
Project Description:	Conduct annual biological sampling in selected reaches of Clear Creek, Cattail Creek, and Devils Hole Creek. It is suggested that permanent sampling stations be established at the following sites: 1. Lower mainstem of Cattail Creek 2. Middle mainstem of Cattail Creek 3. Lower mainstem of Devils Hole Creek 4. Middle mainstem of Devils Hole Creek (below TRF) 5. Devils Hole Creek TRF tributary (next to TRF) 6. Devils Hole Creek firehouse tributary (behind station) 7. Clear Creek below Trident Lakes 8. Clear Creek tributary below PW detention pond
Stream or Subbasin:	Clear Creek, Cattail Creek, and Devils Hole Creek.
Construction Requirements:	None
Project Restrictions:	Sampling shall be conducted annually in September.
Project Priority:	High
Permit Requirements:	None
Long-Term Maintenance:	None
Estimated Project Cost:	\$100-\$150 per sample for analysis costs. Volunteer labor should be utilized for sampling. Initial equipment (surber sampler and support gear) can be purchased for about \$300. One man-week of supervisory time required per year.

Stream Sampling Protocol for Benthic Macroinvertebrates

I. Selection of Sample Reach

Selection of reaches for intensive study, including sampling of invertebrates, results from an interaction of study goals and watershed condition. The dimensions of those decisions are too complex for detailed discussion here. Throughout this document, I assume that the primary goal of studies that use this protocol is to measure and understand the influence of humans in watersheds. This assumption means that patterns of variation in space and time that relate to seasonal or between-year climatic variation are of less interest than the response of stream organisms to the actions of human society.

II. Selection of Sampling Site Within a Study Reach

The distribution of invertebrates in small streams is very patchy. Associations between invertebrates and stream microhabitats (riffles, pools, raceways; erosional or depositional areas, etc.) are the primary driver of that patchiness. For that reason, our standard protocol calls for collection of three replicate surber samples as follows:

1. Sample in the "best" natural riffle segment within a study reach. This does not result in exact matching of substrates condition in all streams. Sediment types may vary among streams, especially in association with changing influence of human actions within and among streams. Ideal sampling locations consist of rocks 5 to 10 cm in diameter sitting on top of pebbles. Substrates dominated by rocks larger than 50 cm in diameter should be avoided.

2. Sample within the main flow of the stream.

3. Sample at water depths of 10 to 40 cm.

4. Depth, flow, and substrate type should be similar for the three replicate samples collected in a riffle.

5. Begin sampling downstream and proceed upstream for each of the three replicates.

III. Sampling Procedures

Sampling teams may range from two to four people. Actual collection of macroinvertebrates requires two people. Others can assist with equipment, labeling collections, and other duties. Sampling procedures for a site as described above should be done as follows:

1. Place the nylon surber net (500-m mesh) on a selected spot with the opening of the net facing upstream. Brace the brass frame and hold it firmly on the substrate surface.

2. While one person holds the brass frame under water, the other person lifts the larger rocks resting within the frame and washes off organisms crawling on or attached loosely to the rock surfaces into the stream so they drift into the nylon net.. After cleaning, the rocks are placed in a bucket for further picking on the shore.

3. After large rocks from within the frame are removed, cleaned, and placed in the bucket, thoroughly disturb the pebble layer with a small rake, large spike, or similar implement. This disturbance should extend to a depth of about 10 cm to loosen organisms in the interstitial spaces to wash them into the net. While disturbing the sediment, collect large rocks with organisms and place them in the bucket.

4. After the pebble layer is disturbed for about 1 minute, slowly lift the brass frame off the sediment and tilt the net up and out of the water while keeping the open end upstream. The organisms trapped in the net are then washed into the receptacle.

5. One person carries the net and the other carries the bucket to the shore for picking off organisms or transferring them to alcohol for later sorting, counting, an identification. The removable receptacle makes this task relatively simple compared to net without a removable receptacle. Great are should be taken in this step to collect and preserve all organisms from the suber sampler as well as from the rocks and water in the bucket. Use of a magnifying glass and forceps is essential.

6. After organisms are collected, the sample jar should be properly labeled with date, sample location (name and number), and replicate number.

7. Rinse the net THOROUGHLY after each sample to avoid cross contamination of samples.

IV. Time of Sample Collection

Macroinvertebrate species composition and population sizes vary substantially through the seasonal cycles that rivers experience. Because our primary interest in is assessing the influence of human actions, we collect samples during a short period, generally in late summer or early autumn. Our goals in sampling are to collect representative samples of stream invertebrates while we

1. Avoid activities that endanger field crews.
2. Standardize seasonal context
3. Maximize efficiency of the sampling method
4. Avoid periods where flows are likely to variable.

In the Pacific Northwest, sample in September. Shifting the sample period a bit earlier into August or extending it into October is acceptable. But all samples should be collected in a period of not more than 4 weeks before the onset of autumn rains.

V. Sample Analysis

Macroinvertebrate samples should be analyzed by a qualified biological sampling laboratory. The benthic index of biotic integrity (B-IBI) for the PNW (Karr, 1996) should be utilized as the primary measurement tool.

NSB-BANGOR SWM PROJECT SUMMARY

Project Location: Middle tributary of Cattail Creek; upper segment at NSB boundary road crossing.

Project Description: Install culvert under NSB boundary road to accommodate higher flows anticipated because of upstream (off-base) development.

Stream or Subbasin: Cattail Creek

Construction Requirements: Utilize Naval Construction Battalion personnel and heavy equipment to install new culvert and regrade roadbed. New culvert should be 2-4 feet in diameter to have sufficient Installation should be performed during summer, low-flow period (July–September).

Project Priority: Low to moderate (within next 3 years).

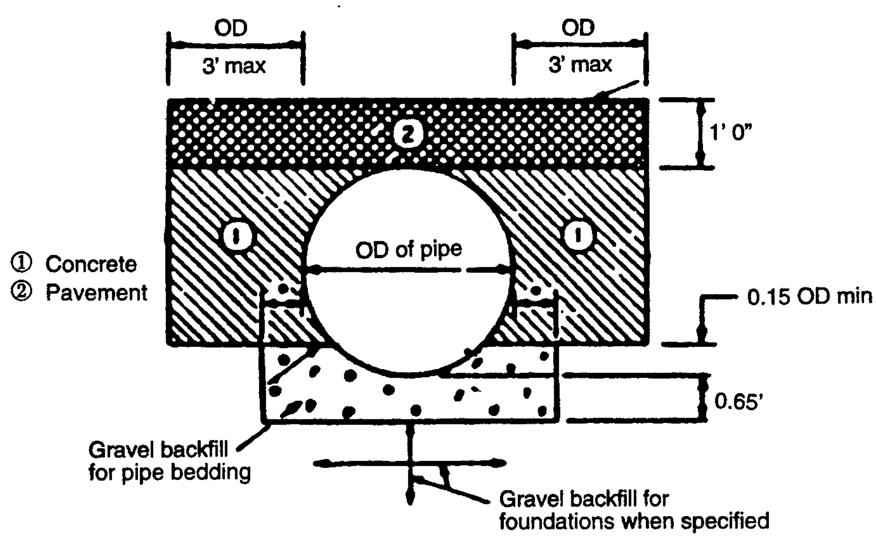
Permit Requirements: Joint Aquatic Resource (JARPA) Hydraulic Project Permit.

Long-Term Maintenance: Periodic inspection and/or removal of debris.

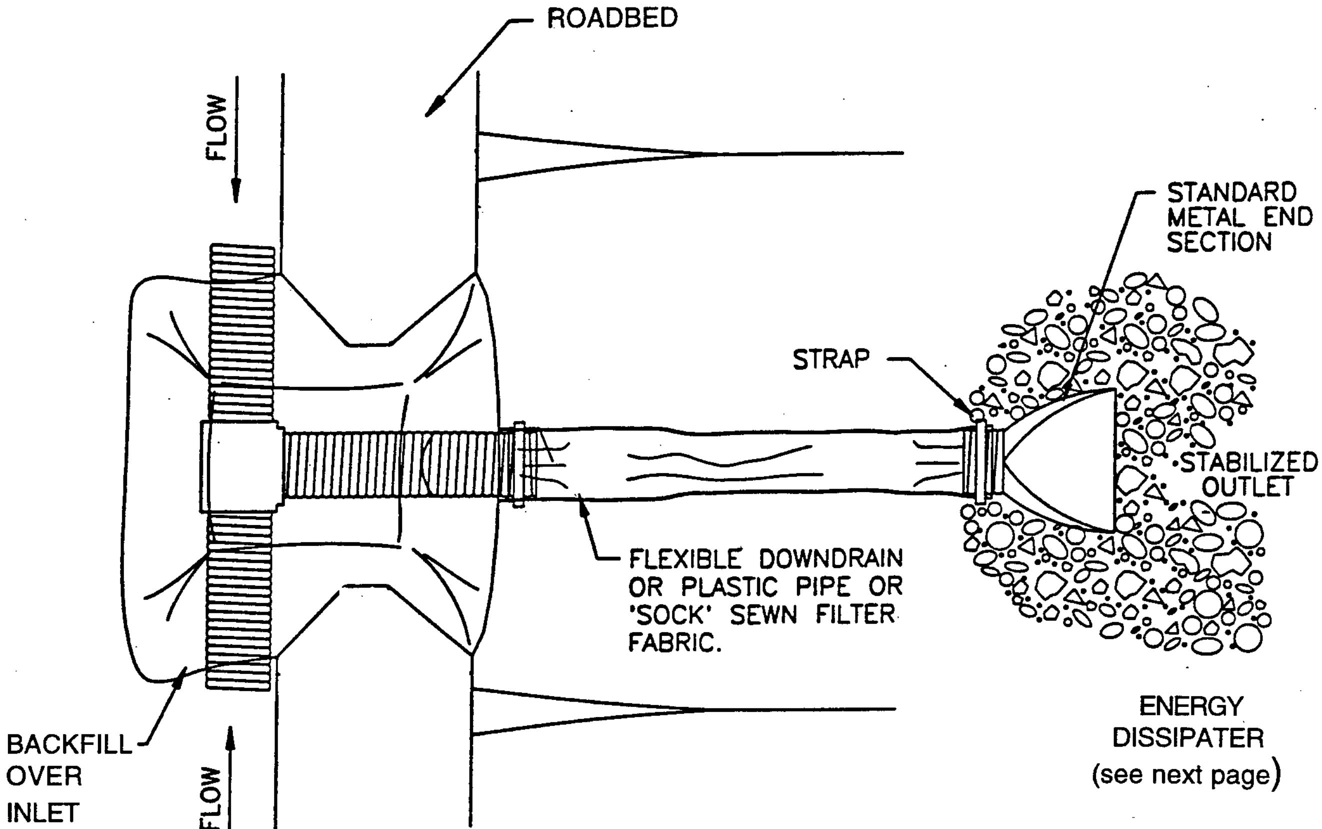
Estimated Project Cost: $1000 for culvert. Estimate 2–3 days of work using CB and/or PW personnel.

PROJECT DIAGRAM

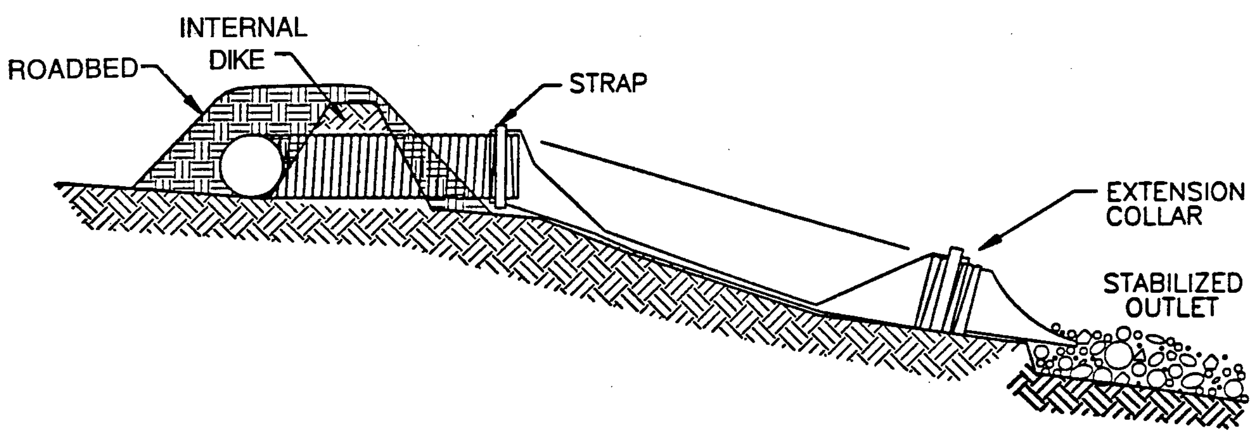
(Also see following pages)



CULVERT INSTALLATION

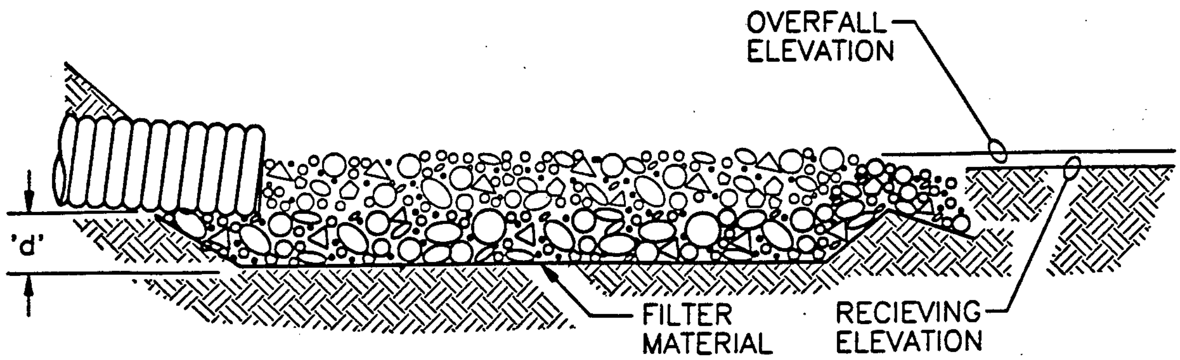


PLAN VIEW



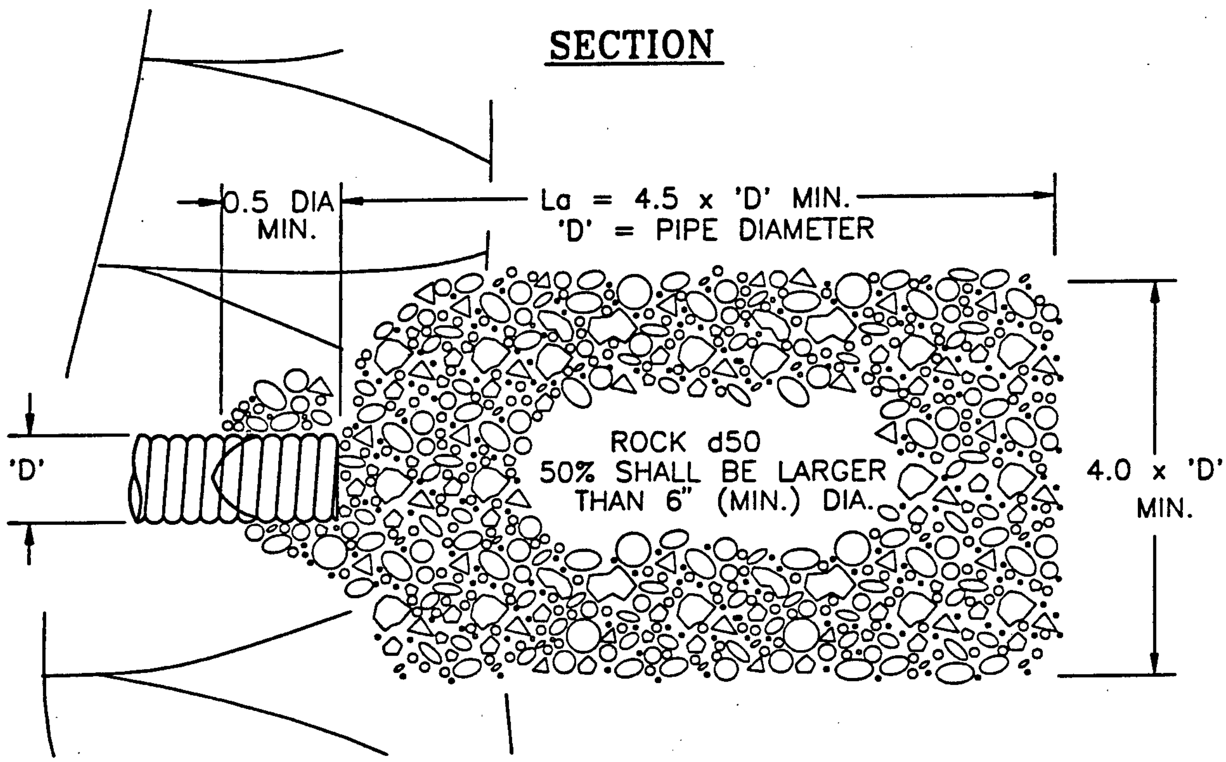
SECTION

ENERGY DISSIPATER



THICKNESS ('d') = 1.5 x MAX ROCK DIAMETER (6" MIN.)

SECTION



PLAN

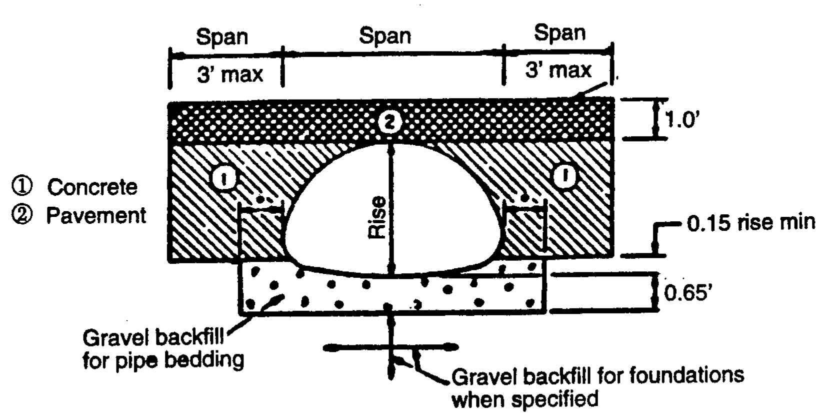
NOTES:

1. 'La' = LENGTH OF APRON. DISTANCE 'La' SHALL BE OF SUFFICIENT LENGTH TO DISSIPATE ENERGY.
2. APRON SHALL BE SET AT A ZERO GRADE AND ALIGNED STRAIGHT.
3. FILTER MATERIAL SHALL BE FILTER FABRIC OR 6" THICK (MIN.) GRADED GRAVEL LAYER.

NSB-BANGOR SWM PROJECT SUMMARY

Project Location:	North tributary of Cattail Creek; upper segment at NSB boundary toad crossing.
Project Description:	Replace undersized culvert under NSB boundary road with arched culvert to accommodate higher flows anticipated because of upstream (off-base) development and to allow migration of native salmonids.
Stream or Subbasin:	Cattail Creek
Construction Requirements:	Utilize Naval Construction Battalion personnel and heavy equipment to remove existing culvert, install new culvert , and regrade roadbed. New culvert should be 6–8 feet in diameter to have sufficient capacity for estimated future stormwater flows.
Project Restrictions:	Installation should be performed during summer, low-flow period (July–September).
Project Priority:	Low to moderate (within next 3 years).
Permit Requirements:	Joint Aquatic Resource (JARPA) Hydraulic Project Permit.
Long-Term Maintenance:	Periodic inspection and/or removal of debris.
Estimated Project Cost:	$1000 for culvert. Estimate 2–3 days of work using CB and/or PW personnel.

PROJECT DIAGRAM



TYPICAL ARCHED CULVERT INSTALLATION

Project Location:	South tributary of Cattail Creek; upper segment at NSB boundary road crossing.
Project Description:	Repair the bridge crossing Cattail Creek at the NSB boundary road. Road runoff stormwater-conveyance system must be re-routed to prevent future washouts and minimize impact on stream. Damage to stream channel and valley side slope from last winter's storms should be repaired as well.
Stream or Subbasin:	Cattail Creek
Construction Requirements:	During the planned repair of the bridge and road over the south tributary of Cattail Creek, the stormwater-conveyance system for boundary road runoff should be rerouted to an section of the stream downstream of the present crossing. The steep topography of this segment precludes construction of a R/D facility; however, it may be possible to pipe runoff to a energy dissipater channel prior to allowing it to flow into the stream channel. Water quantity and high energy are of greater concern than water quality in this case. The valley side slopes and stream banks through this segment of the stream must also be stabilized and revegetated upon completion of the bridge and road repair.
Project Restrictions:	Installation should be performed during summer, low-flow period (July–September).
Project Priority:	High (should be complete before winter of 97–98).
Permit Requirements:	None
Long-Term Maintenance:	Periodic inspection and repair as required.
Estimated Project Cost:	N/A (project is under way).

PROJECT DIAGRAM

(N/A)

NSB-BANGOR SWM PROJECT SUMMARY

Project Location: Outlet of Cattail Lake

Project Description: Construct fishway(s) at the outlet of Cattail Lake into Hood Canal to support native anadromous fish (coho and chum) runs. There are presently two outlet structures on the lake; therefore a fish ladder could be constructed on one outlet while the other serves as the outlet. Prior to beginning this project, contact should be made with the USFWS, WDF, and local Native American tribal fisheries biologists to establish a stocking plan to restore coho and chum runs to Cattail Creek. On-base fishermen and dependent school children could be included in this effort as volunteers.

Stream or Subbasin: Cattail Creek

Construction Requirements: Contract for design and construction of a fishway(s).

Project Restrictions: Construction should occur during summer (dry) season.

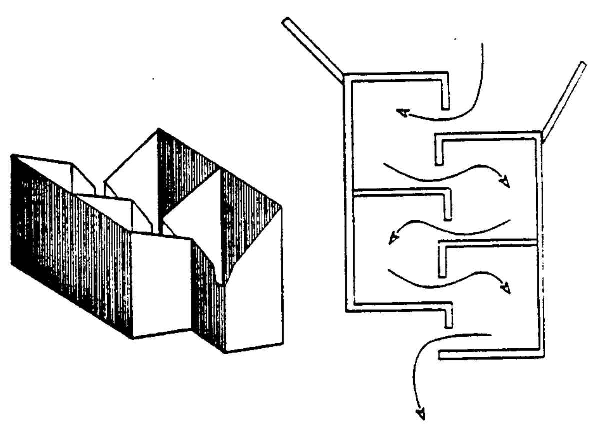
Project Priority: Moderate to high

Permit Requirements: Joint Aquatic Resource (JARPA) Hydraulic Project Permit

Long-Term Maintenance: Periodic inspection and/or removal of debris

Estimated Project Cost: $25,000

PROJECT DIAGRAM



NSB-BANGOR SWM PROJECT SUMMARY

Project Location:	Trident Lakes stormwater R/D facility
Project Description:	Naturalize area surrounding Trident Lakes and provide thermal (shading) moderation for downstream stream segments.
Stream or Subbasin:	Clear Creek (South Tributary)
Construction Requirements:	Utilize Naval Construction Battalion personnel and heavy equipment to remove nonnative vegetation and replant with native trees, shrubs, and ground cover. Volunteers can be used to perform landscaping and planting after heavy equipment prep-work is complete.
Project Restrictions:	None
Project Priority:	Moderate (w/in next 3 years).
Permit Requirements:	None
Long-Term Maintenance:	Control invasive plants (blackberries and Scotch broom) until native vegetation dominates.
Estimated Project Cost:	$5000 for native trees and shrubs. Two weeks of labor using CB and/or PW personnel, as well as volunteers.

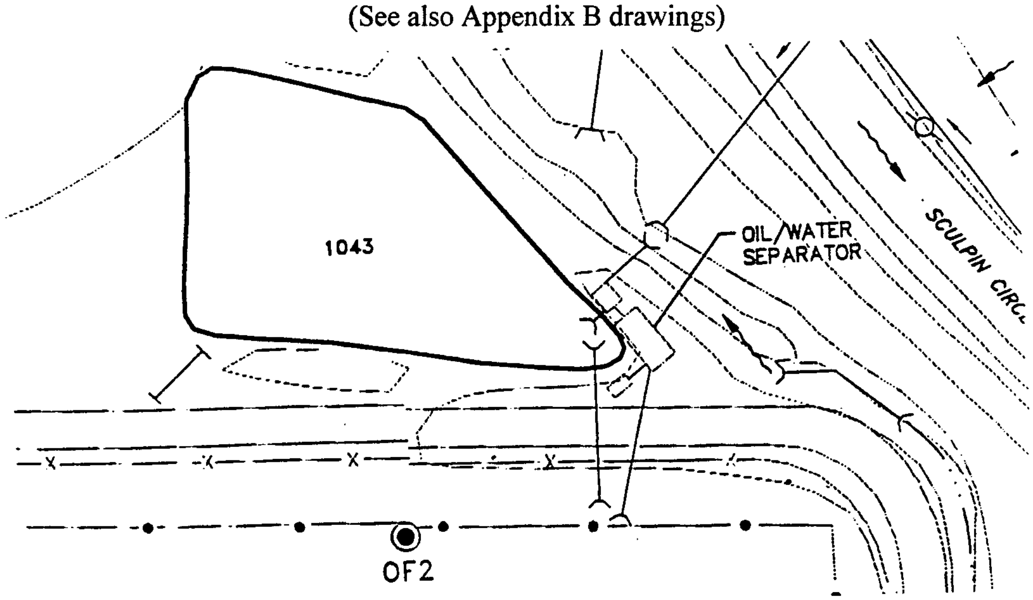
PROJECT DIAGRAM

N/A

NSB-BANGOR SWM PROJECT SUMMARY

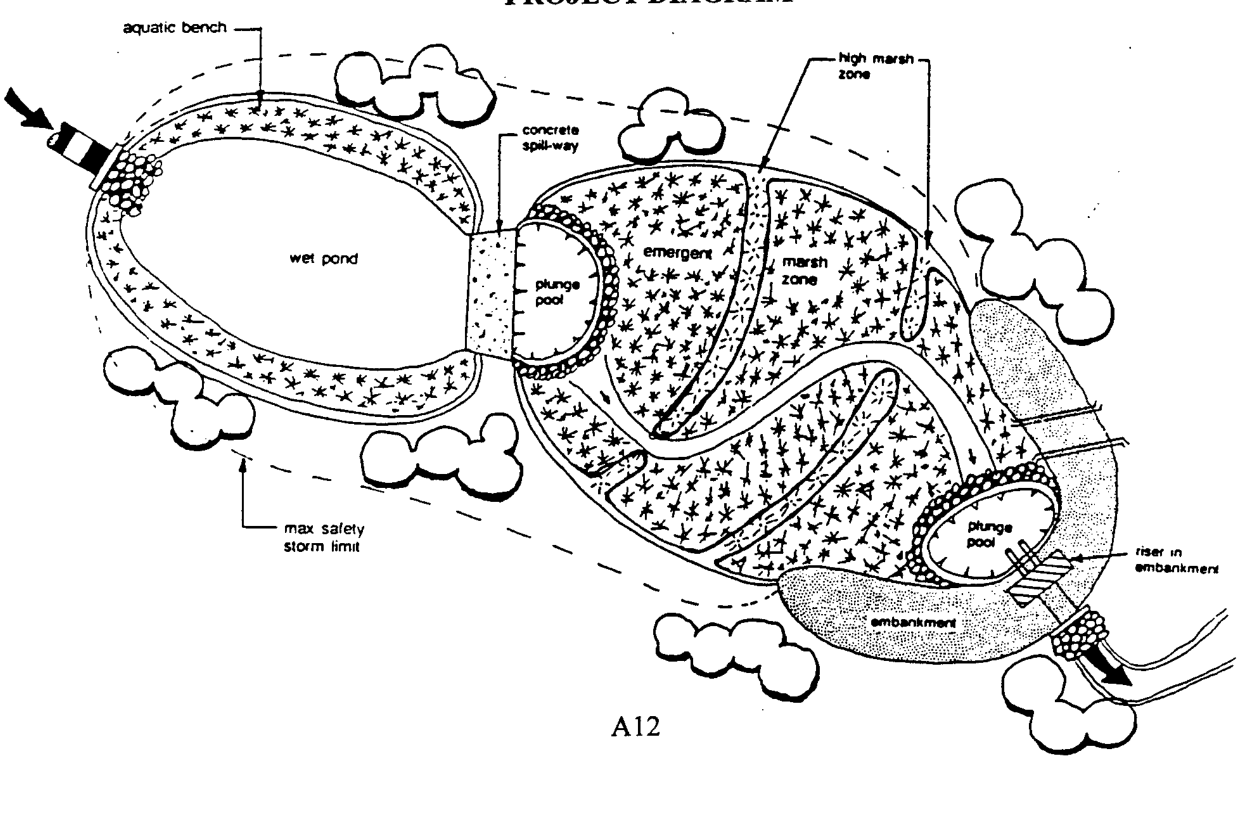
Project Location:	Public Works industrial area stormwater R/D facility
Project Description:	1. Naturalize area surrounding R/D facility and provide thermal (shading) moderation for downstream stream segments. 2. Improve in-stream flow conditions, provide stream bank stabilization, and revegetate the riparian
Stream or Subbasin:	Clear Creek
Construction Requirements:	1. Utilize volunteers to perform landscaping and planting of native trees, shrubs, and ground cover. 2. Reshape stream channel (~2 km) and stream banks and install stream-bank protection. Remove non-native vegetation and replant with native riparian plants. Volunteers can be used to perform channel enhancements and planting after heavy equipment prep-work is complete.
Project Restrictions:	Construction should be performed during summer, low-flow period (July- September). Flow diversion may be required. This project will require close cooperation with Kitsap County SWM and private landowners.
Project Priority:	Moderate to high (w/in next 3 years)
Permit Requirements:	Joint Aquatic Resource (JARPA) Hydraulic Project Permit.
Long-Term Maintenance:	Periodic inspection and repair as required. Control invasive plants (blackberries and Scotch broom) until native vegetation dominates.
Estimated Project Cost:	\$5000 for native trees and shrubs. Two weeks of labor using CB and/or PW personnel, as well as volunteers.

PROJECT DIAGRAM
(See also Appendix B drawings)



Project Location:	Upper base stormwater treatment facility
Project Description:	Construct a stormwater treatment wetland (quality and quantity control) in the open area just inside the base boundary between Sunfish drive and Clear Creek Road. This area has wetland soil and vegetation characteristics and was probably a headwater wetland for a tributary of Clear creek that now begins to the east of Clear Creek Road. This facility will serve the older portion of the upper base including those impervious areas around Tautog Circle and the Main Gate as well. This facility will drain to Clear Creek via the existing off-base stormwater conveyance network. This BMP should improve water quality and reduce runoff volume entering a tributary to Clear Creek that currently supports native salmonids.
Stream or Subbasin:	Clear Creek
Construction Requirements:	Contract for design and construction of wetland treatment facility.
Project Restrictions:	Project should be accomplished during summer season.
Project Priority:	Low-Moderate (in the next 5 years)
Permit Requirements:	None
Long-Term Maintenance:	Periodic inspection, upkeep, and landscaping
Estimated Project Cost:	$20,000-30,000

PROJECT DIAGRAM



NSB-BANGOR SWM PROJECT SUMMARY

Project Location:	Various highly impervious, transportation-related "hot spots" within NSB-Bangor.
Project Description:	Install self-contained, on-site stormwater-treatment BMPs at the following locations: 1. NSB service station/car wash/hobby shop 2. Public Works industrial area 3. NSB motor pool 4. Main TRF parking area 5. Main SWFPAC parking area
Stream or Subbasin:	Clear Creek and Devils Hole Creek
Construction Requirements:	Contract with private firm(s) to install BMPs.
Project Restrictions:	None
Project Priority:	Moderate
Permit Requirements:	None
Long-Term Maintenance:	Periodic sampling, inspection, and cleaning.
Estimated Project Cost:	Per-unit cost estimates (to treat one acre of impervious surface) for the following commercially available systems are provided as a guide: 1. CSF Compost-Filter Media System \$25,000 (Figure 34) 2. StormTreat System (STS) Modular Wetland \$20,000 (Figure 35) 3. Multi-Chamber Treatment Train (MCTT) \$30,000 (Figure 36)

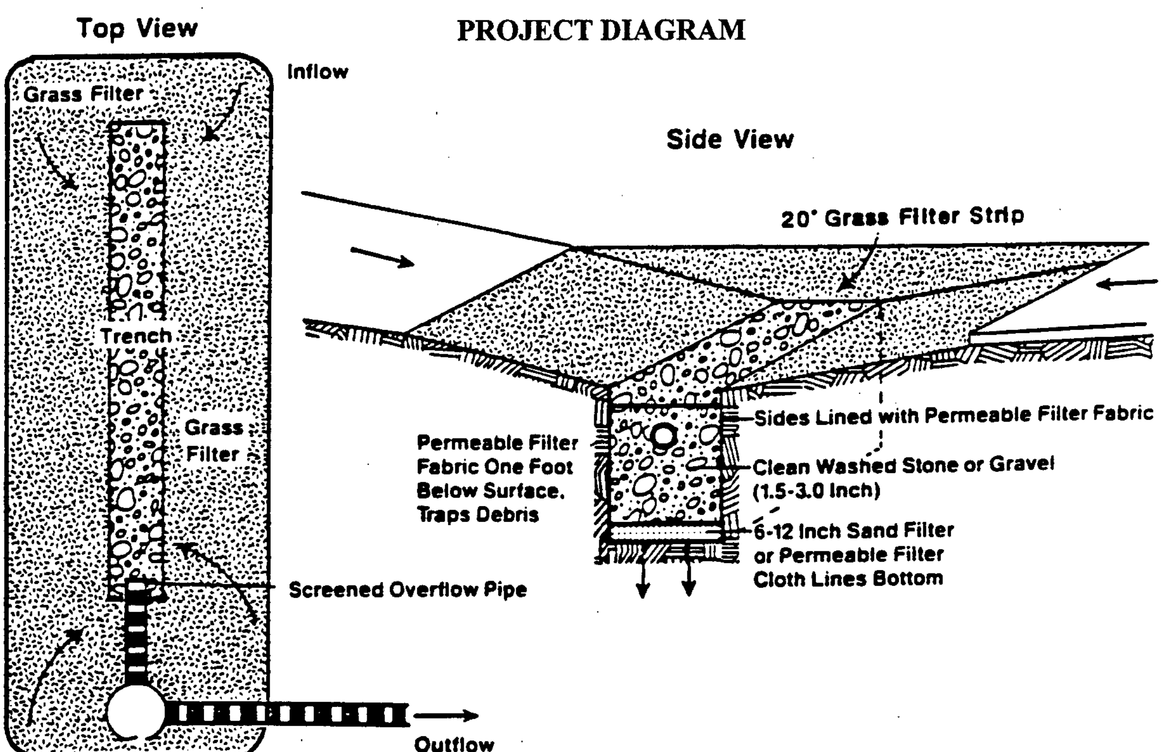
PROJECT DIAGRAM

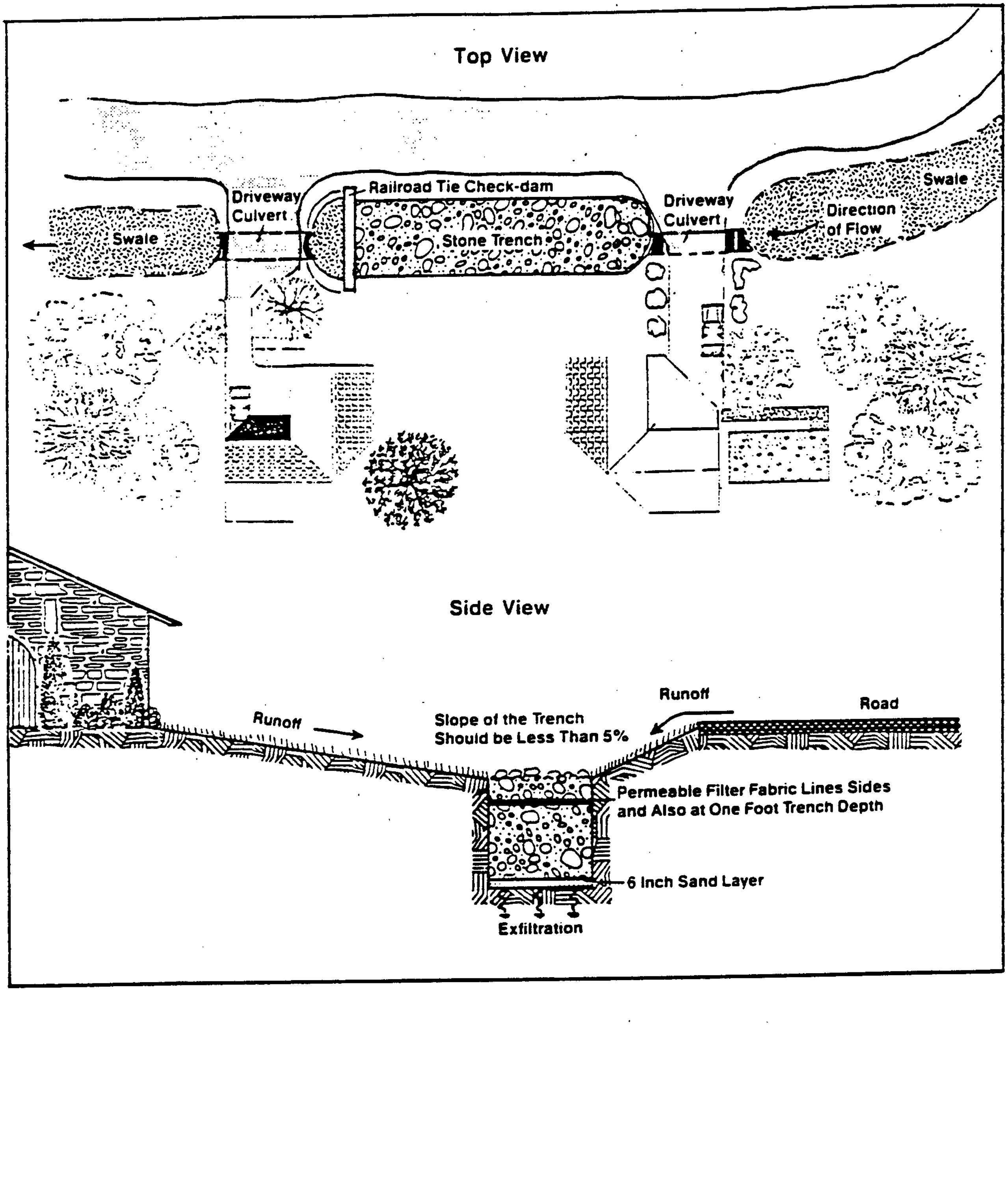
(see Figures 34–36 in text)

NSB-BANGOR SWM PROJECT SUMMARY

Project Location:	West Family Housing stormwater runoff treatment; Best Management Practices (BMPs)
Project Description:	Construct infiltration swales and pocket wetlands between residential subdivisions in the West Family Housing area.
Stream or Subbasin:	West Family Housing (no stream subbasin)
Construction Requirements:	Utilize USN Construction Battalion (CB) personnel, public works employees, and resident volunteers to construct and maintain individual stormwater-treatment BMPs throughout the West Family Housing area. Heavy equipment will be required for some projects, although it is expected that most can be done by hand. Volunteers should be utilized to plant native vegetation as required. This will help to build community support and educate residents with regard to stormwater management and NPS pollution control.
Project Restrictions:	Project should be accomplished during summer (dry) season
Project Priority:	High (within next 1–2 years)
Permit Requirements:	None
Long-Term Maintenance:	Periodic inspection, upkeep, and landscaping
Estimated Project Cost:	An average of $5,000 per project for materials plus one week of manpower (on average) for each project using CB and/or PW personnel, as well as resident volunteers.

PROJECT DIAGRAM




Top View
Railroad Tie Check-dam
Driveway Culvert
Driveway Culvert
Swale
Swale
Stone Trench
Direction of Flow
Side View
Runoff
Runoff
Road
Slope of the Trench Should be Less Than 5%
Permeable Filter Fabric Lines Sides and Also at One Foot Trench Depth
6 Inch Sand Layer
Exfiltration

NSB-BANGOR SWM PROJECT SUMMARY

Project Location:	West Family Housing; stormwater-treatment facility; regional detention pond to the west of Florida Drive
Project Description:	Construct a regional stormwater treatment (quantity and quality) facility to the west of Florida Drive. This BMP is already partially constructed (outlet control structure) but is not sized to properly treat runoff from this area. This facility will service most of the newer family housing subdivisions located on the west side of Thresher Avenue. This includes portions of Alabama Court and Florida Court, Sam Houston Drive, Michigan Drive, and Florida Drive. This facility drains to Hood Canal via natural (off-base) drainage.
Stream or Subbasin:	West Family Housing (no stream subbasin)
Construction Requirements:	Utilize USN Construction Battalion (CB) personnel, public works employees, and/or civilian contractors to build a pond, stormwater-conveyance channels, and an outflow energy dissipation structure. Safety fencing will also be required.
Project Restrictions:	Project should be accomplished during summer (dry) season
Project Priority:	High (within next 1–2 years)
Permit Requirements:	None
Long-Term Maintenance:	Periodic inspection, upkeep, and landscaping
Estimated Project Cost:	$25,000

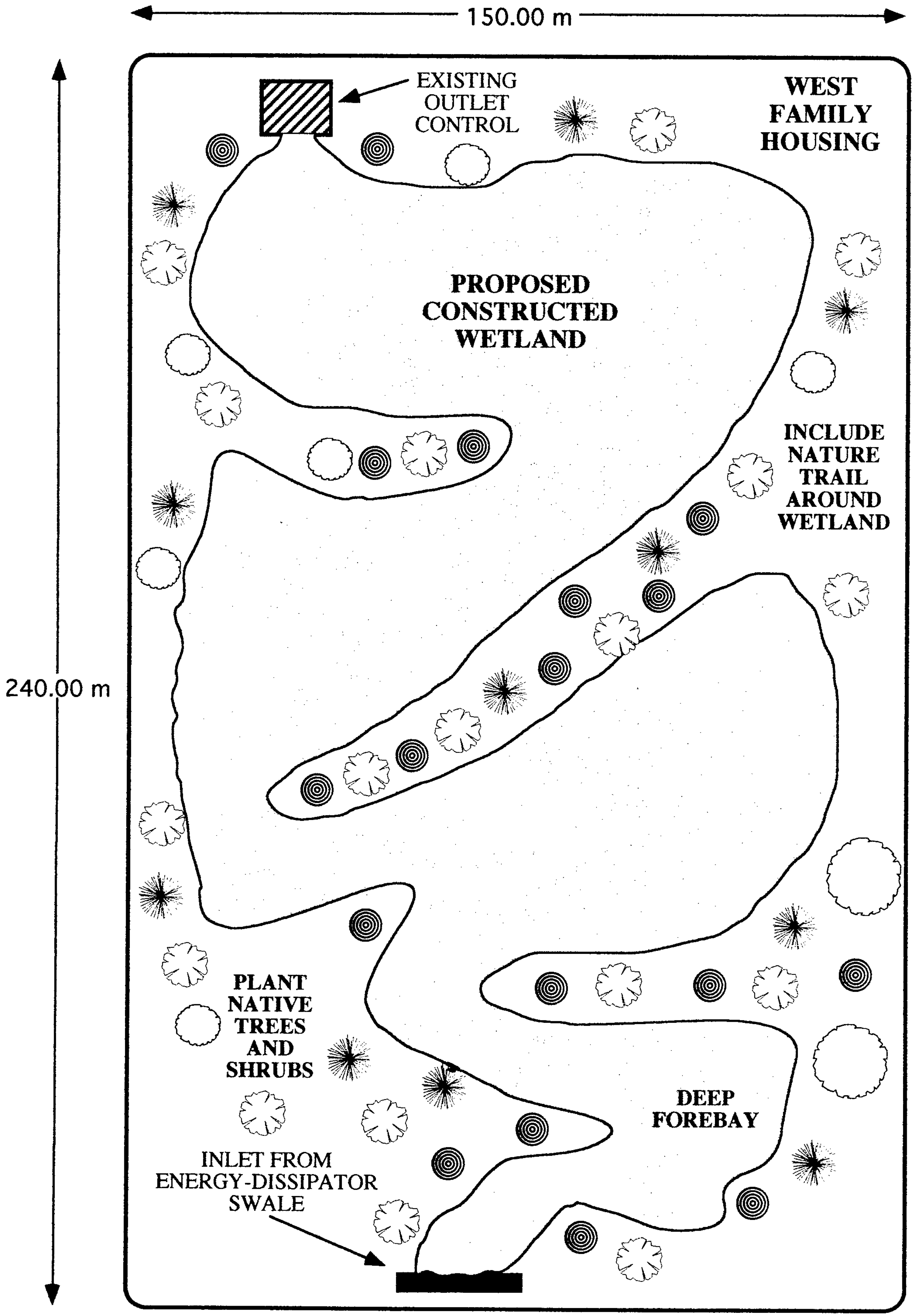
PROJECT DIAGRAM

(N/A)

Project Location:	West Family Housing; stormwater-treatment facility; regional extended detention wetland between (west) Georgia Court and Alabama Court.
Project Description:	Construct a stormwater-treatment wetland (quality and quantity control) in an open area to the west of family housing. This area has an outlet-control structure in place and is already serving as a stormwater detention volume, but is not properly designed for optimal treatment. This facility will serve Alabama Court and Georgia Court as well as portions of Gudgeon Avenue. This facility drains to Hood Canal via natural (off-base) drainage.
Stream or Subbasin:	West Family Housing (no stream subbasin)
Construction Requirements:	Contract for design and construction of wetland treatment facility in the area between Alabama and Georgia Courts.
Project Restrictions:	Project should be accomplished during summer (dry) season
Project Priority:	High (within next 1–2 years)
Permit Requirements:	None
Long-Term Maintenance:	Periodic inspection, upkeep, and landscaping
Estimated Project Cost:	$50,000

PROJECT DIAGRAM

(see next page)


150.00 m
240.00 m
EXISTING
OUTLET
CONTROL
WEST
FAMILY
HOUSING
PROPOSED
CONSTRUCTED
WETLAND
INCLUDE
NATURE
TRAIL
AROUND
WETLAND
PLANT
NATIVE
TREES
AND
SHRUBS
DEEP
FOREBAY
INLET FROM
ENERGY-DISSIPATOR
SWALE

NSB-BANGOR SWM PROJECT SUMMARY

Project Location: SWFPAC tributary of Devils Hole Creek; headwaters

Project Description: Modify existing stormwater-control and treatment facility to minimize downstream impacts of stormwater runoff from SWFPAC impervious areas.

Stream or Subbasin: Devils Hole Creek

Construction Requirements: Clear brush and young trees from within the stormwater-treatment basin. Using heavy equipment, install 2–3 check-dams within the basin perpendicular to the storm-flow axis. Design and install new outlet control structure. Construct energy-dissipation channel downstream of outlet using quarry rock (heavy equipment required).

Project Restrictions: Construction should be done during summer (dry) season.

Project Priority: Moderate to high

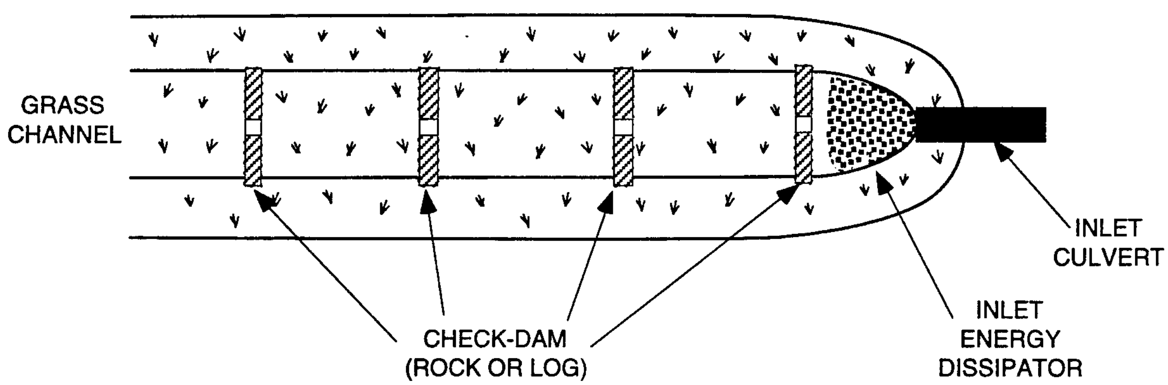
Permit Requirements: None

Long-Term Maintenance: Periodic inspection, brush clearing, and debris removal.

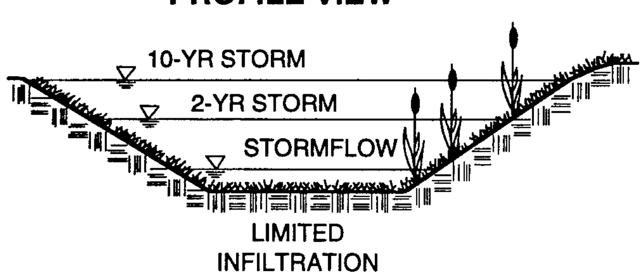
Estimated Project Cost: $5,000 for material and one week of manpower and heavy equipment using CB and/or PW personnel.

PROJECT DIAGRAM

PLAN VIEW



PROFILE VIEW



Biofiltration Swale

Project Location:	SWFPAC tributary of Devils Hole Creek; upper segment
Project Description:	Runoff from SWFPAC has incised the headwater channel of the tributary. The problem area is just upstream of a headwater wetland where the actual stream channel begins. This segment does not contain salmonid habitat, but influences downstream habitat (fine sediment and high flows).
Stream or Subbasin:	Devils Hole Creek
Construction Requirements:	Utilize Naval Construction Battalion personnel and heavy equipment to construct an energy-dissipating channel in the forested area between the upstream BMP and the incision point. Quarry rock and LWD from trees felled on site should be utilized. Regard and fill the incision area and install rock and log check dams as grade-control structures. Clear brush and alders from the clearing and replant with native conifers and ground cover.
Project Restrictions:	Construction should be done during the summer (dry) season.
Project Priority:	Moderate to high
Permit Requirements:	None
Long-Term Maintenance:	Periodic inspection and debris removal.
Estimated Project Cost:	$2,500 for material and one week of manpower and heavy equipment using CB and/or PW personnel.

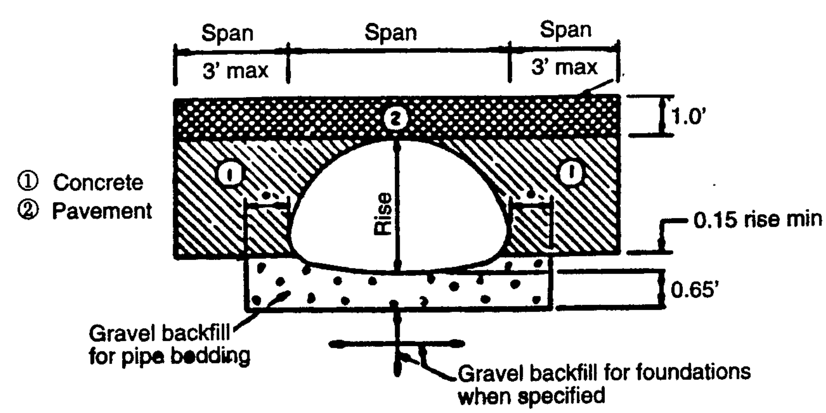
PROJECT DIAGRAM

N/A

Project Location:	SWFPAC tributary of Devils Hole Creek; middle segment between Escolar Road and utility corridor access road.
Project Description:	Culverts (3) in this moderately steep segment of the SWFPAC tributary are undersized for current storm-flow conditions and are fish-passage barriers (owing to perched outlets and downcutting of streambed). The goal of this project will be to improve instream flow conditions, increase culvert storm-flow capacity, and encourage potential salmonid utilization of SWFPAC tributary.
Stream or Subbasin:	Devils Hole Creek
Construction Requirements:	Utilize Naval Construction Battalion personnel and heavy equipment to remove existing culverts, install new culverts, and regrade roadbeds. New arched culverts should be 2–4 feet in diameter to have sufficient capacity for estimated future stormwater flows. Downstream of each culvert, in-stream grade-control structures will be installed using quarry rock and coniferous logs. The project should be scheduled in sequence starting from the uppermost (Escolar) culvert and working downstream. The two Escolar Road culverts are relatively simple jobs in comparison to the utility road project. A bridge would be more appropriate for this stream crossing, but would be costly (possibly prohibitive).
Project Restrictions:	Construction must be accomplished during summer, low-flow period; flow bypass structures may be required.
Project Priority:	Low to moderate (within next 3–5 years).
Permit Requirements:	Joint Aquatic Resource (JARPA) Hydraulic Project Permit.
Long-Term Maintenance:	Periodic inspection and/or removal of debris.
Estimated Project Cost:	$15,000 for material and three weeks of manpower and heavy equipment using CB and/or PW personnel.

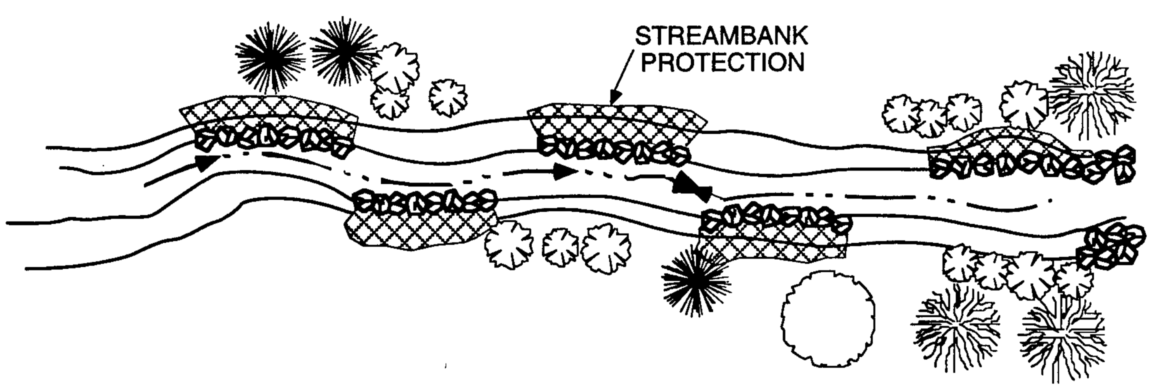
PROJECT DIAGRAM

(See also Figures ____ in text)



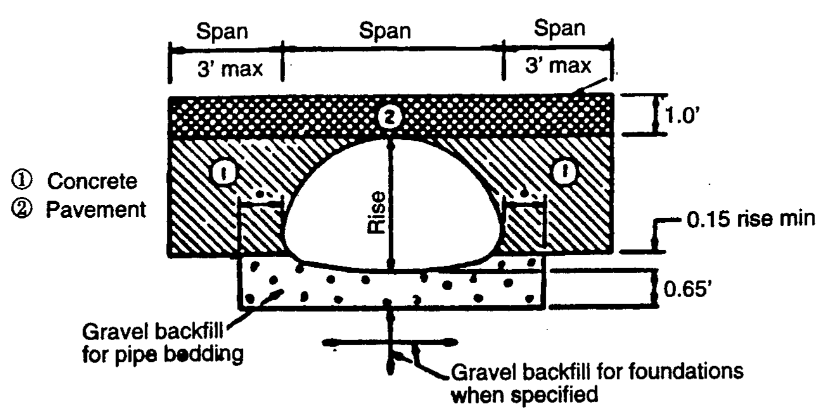
Project Location:	Firehouse tributary of Devils Hole Creek; upper-middle segment (upstream of Snook Road crossing).
Project Description:	Improve in-stream flow conditions, provide stream-bank stabilization, enhance in-stream habitat complexity, and revegetate the riparian zone upstream of Snook Road.
Stream or Subbasin:	Devils Hole Creek
Construction Requirements:	Utilize Naval Construction Battalion personnel and heavy equipment to reshape stream channel (~200 m) and stream banks. Install stream-bank protection and in-stream structure (LWD). Remove nonnative vegetation and replant with native riparian plants. Volunteers can be used to perform channel enhancements and planting after heavy equipment prep-work is complete.
Project Restrictions:	Construction should be performed during summer, low-flow period (July–September). Flow diversion will be required.
Project Priority:	Moderate to high (within next 2 years).
Permit Requirements:	Joint Aquatic Resource (JARPA) Hydraulic Project Permit.
Long-Term Maintenance:	Periodic inspection and enhancement. Control invasive plants (Blackberries and Scotch broom) until native vegetation dominates.
Estimated Project Cost:	$2,500 for material and one week of manpower/heavy equipment using CB and/or PW personnel.

PROJECT DIAGRAM



Project Location:	Firehouse tributary of Devils Hole Creek; middle segment at intersection of Snook Road and Sturgeon Street.
Project Description:	Replace undersized road culvert with arched culvert to accommodate higher flows and to enhance migration of native salmonids. Current culvert outlet is buried by sediment deposited by last winter's storms.
Stream or Subbasin:	Devils Hole Creek
Construction Requirements:	Utilize Naval Construction Battalion personnel and heavy equipment to remove existing culvert, install new culvert, and repave roadbed. New culvert should be 4–6 feet in diameter to have sufficient capacity for estimated future stormwater flows. Alternatively, this project could be contracted to a civilian firm.
Project Restrictions:	Construction should be performed during summer, low-flow period (July–September). Flow diversion will be required.
Project Priority:	High (perform as soon as possible—current culvert is a complete barrier to salmonid migration).
Permit Requirements:	Joint Aquatic Resource(JARPA) Hydraulic Project Permit.
Long-Term Maintenance:	Periodic inspection and removal of debris.
Estimated Project Cost:	$5,000 for material and one week of manpower and heavy equipment using CB and/or PW personnel.

PROJECT DIAGRAM

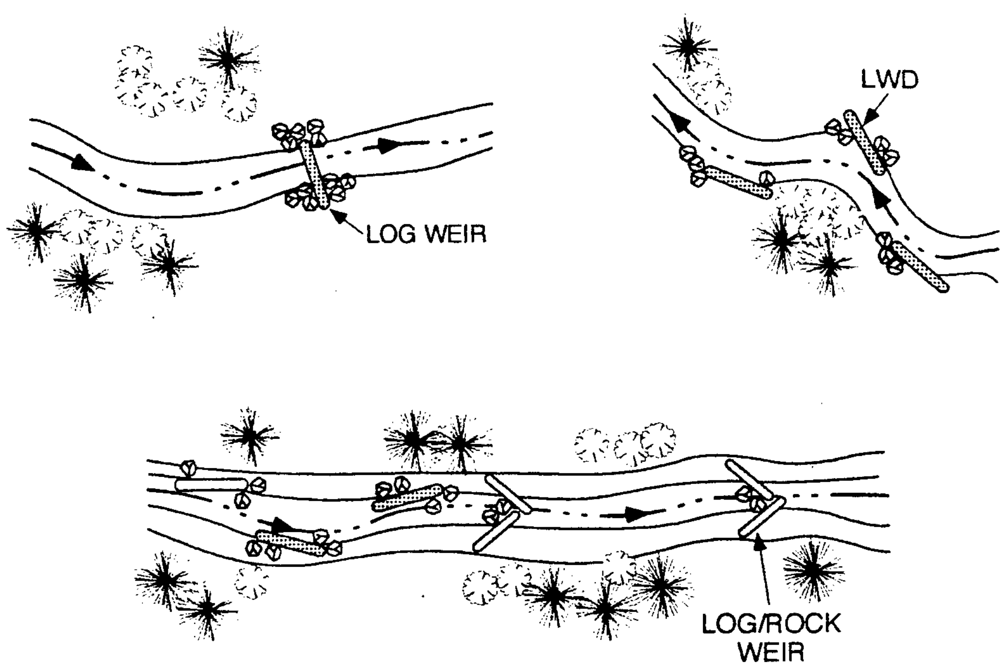


TYPICAL ARCHED CULVERT INSTALLATION

NSB-BANGOR SWM PROJECT SUMMARY

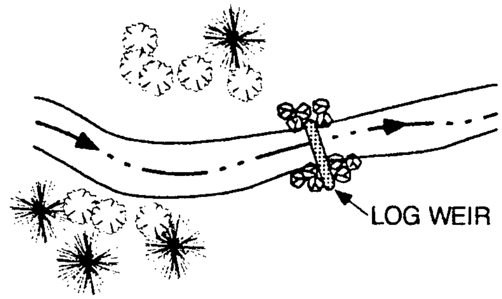
Project Location:	Firehouse tributary of Devils Hole Creek; lower-middle segment (downstream of Sturgeon Street crossing).
Project Description:	Improve in-stream flow conditions, provide stream-bank stabilization, and revegetate the riparian zone.
Stream or Subbasin:	Devils Hole Creek
Construction Requirements:	Reshape stream channel (100 m) and stream banks and install stream-bank protection. Remove nonnative vegetation and replant with native riparian plants. Volunteers can be used to perform channel enhancements and planting after heavy equipment prep-work is complete.
Project Restrictions:	Construction should be performed during summer, low-flow period (July–September). Flow diversion will be required.
Project Priority:	Moderate (within next 3 years).
Permit Requirements:	Joint Aquatic Resource (JARPA) Hydraulic Project Permit.
Long-Term Maintenance:	Periodic inspection. Control invasive plants (blackberries) until native vegetation dominates.
Estimated Project Cost:	$2,500 for material and one week of manpower and heavy equipment using CB and/or PW personnel.

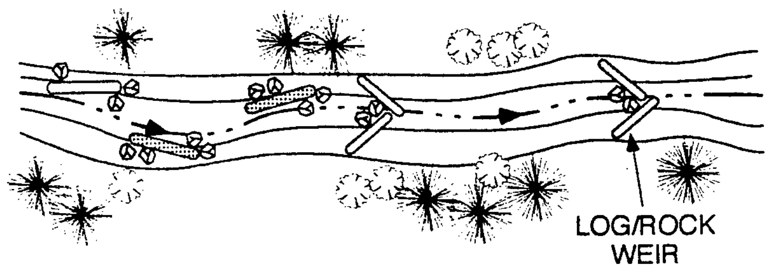
PROJECT DIAGRAM

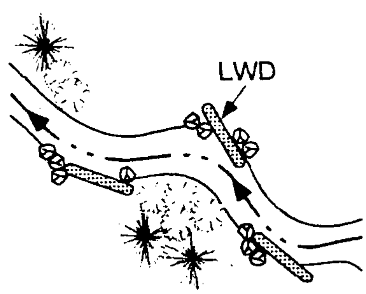


Project Location:	TRF tributary of Devils Hole Creek; upper-middle segment (upstream of Trigger Avenue crossing).
Project Description:	1. Improve flow conditions, in-stream salmonid habitat, and the riparian corridor in the segment of Devils Hole Creek that runs between Snook Road and Trigger Avenue. 2. Replace culverts in this segment with arched culverts or bridges to accommodate larger storm flows and enhance native salmonid migration. 3. Reclaim access road and TRF overflow parking-lot area as riparian corridor and floodplain. This part of the project is a major, long-term effort that can be considered *optional*.
Stream or Subbasin:	Devils Hole Creek
Construction Requirements:	1. Naturalize stream channel, install grade-control and fish-passage weirs, and replant riparian corridor with native vegetation. This project will require a minimum of heavy equipment, mostly for construction-material hauling and placement. This project could be accomplished with CB and/or volunteer labor and equipment. 2. Utilize Naval Construction Battalion personnel and heavy equipment to remove existing culvert, install new culvert, and regrade roadbed. Arched culvert should be 2–4 feet in stormwater flows. 3. Contract for the redesign and construction of the east end of the TRF overflow parking area, including removal of the Trigger Avenue access road, removal of paved surfaces, and restoration of the riparian zone and floodplain area.
Project Restrictions:	Construction should be performed during summer, low-flow period (July–September). Flow diversion may be required.
Project Priority:	Moderate (within next 3 years).
Permit Requirements:	Joint Aquatic Resource (JARPA) Hydraulic Project Permit.
Long-term Maintenance:	Periodic inspection. Control invasive plants (blackberries) until native vegetation dominates.
Estimated Project Cost:	$10,000 for material and two weeks of manpower and heavy equipment using CB and/or PW personnel w/o option #3. $25,000 for material and one month of manpower and heavy equipment using CB and/or PW personnel w/option #3.

PROJECT DIAGRAM


LOG WEIR

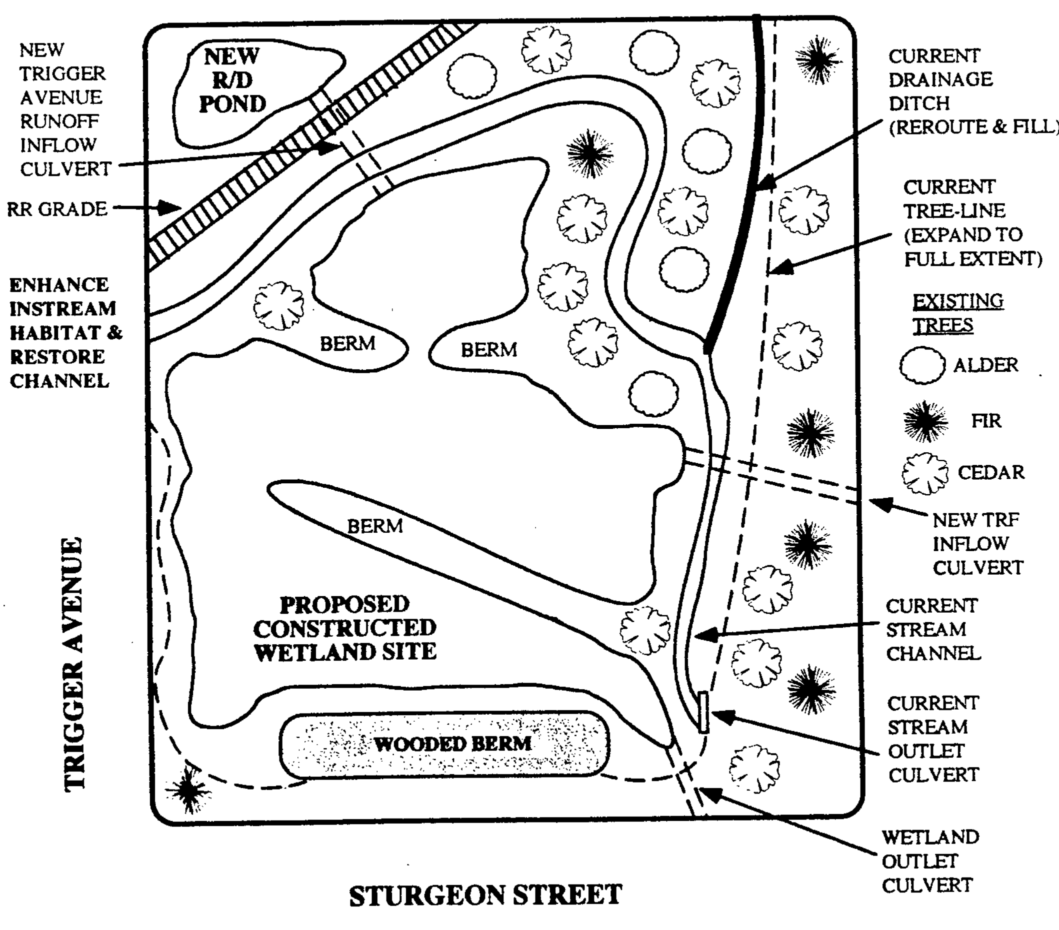

LOG/ROCK
WEIR


LWD

NSB-BANGOR SWM PROJECT SUMMARY

Project Location:	TRF tributary of Devils Hole Creek; middle segment.
Project Description:	Construct a stormwater-treatment wetland in the area between Trigger Avenue, Sturgeon Street, and the TRF parking area. This area is currently partially wooded and already has natural wetland characteristics including hydric soil and wetland vegetation.
Stream or Subbasin:	Devils Hole Creek
Construction Requirements:	See attached estimated design criteria.
Project Restrictions:	Construction should be performed during summer, dry period (July–September).
Project Priority:	Moderate to high (within next 3 years).
Permit Requirements:	None
Long-term Maintenance:	Periodic inspection and control of invasive vegetation.
Estimated Project Cost:	$50,000

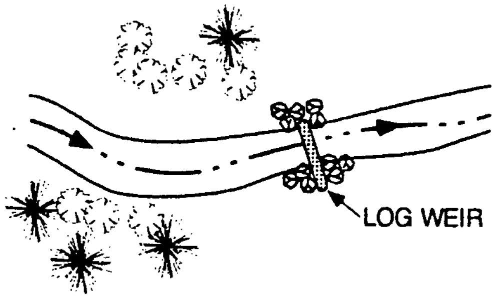
PROJECT DIAGRAM

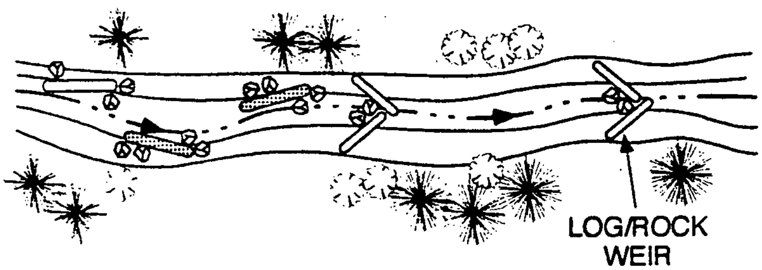


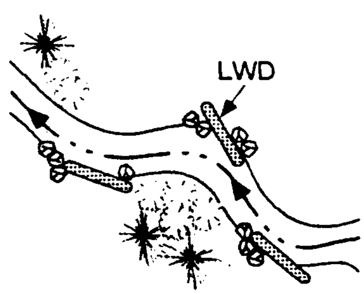
Project Location:	TRF tributary of Devils Hole Creek; lower-middle segment.
Project Description:	1. Improve flow conditions, naturalize in-stream salmonid habitat, and the riparian conditions in the segment of Devils Hole Creek between Trigger Avenue and Sturgeon Street. Current stream channel is "ditched" with overall poor habitat quality. 2. Replace culvert under Trigger Avenue with arched culvert to accommodate larger storm flows and enhance salmonid migration upstream and downstream. 3. Replace culvert under Sturgeon Street with arched culvert to accommodate larger storm flows and enhance salmonid passage.
Stream or Subbasin:	Devils Hole Creek
Construction Requirements:	1. Naturalize stream channel, stabilize stream banks, install in-stream structural elements (LWD), add natural streambed spawning gravel, and replant riparian corridor with native vegetation. This project will require a minimum of heavy equipment, mostly for construction material hauling and placement. This project could be accomplished with CB and/or volunteer labor and equipment. 2. Contract for design and installation of new arched culvert under Trigger Avenue. 3. Contract for design and installation of new arched culvert under Sturgeon Street.
Project Restrictions:	Construction should be performed during summer, low-flow period (July–September). Flow diversion will be required.
Project Priority:	Moderate to high (within next 3 years).
Permit Requirements:	Joint Aquatic Resource (JARPA) Hydraulic Project Permit.
Long-Term Maintenance:	Periodic inspection. Control invasive plants (blackberries) until native vegetation dominates.
Estimated Project Cost:	$15,000 for material and two weeks of manpower and heavy equipment using CB and/or PW personnel.

PROJECT DIAGRAM

(see next page)


LOG WEIR


LOG/ROCK
WEIR


LWD

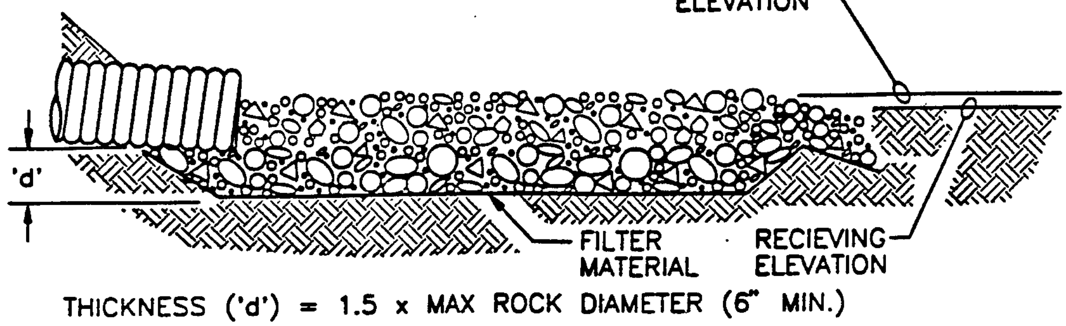
NSB-BANGOR SWM PROJECT SUMMARY

Project Location:	Sturgeon tributary headwaters of Devils Hole Creek; outlet of R/D facility (extended detention wetland pond) at the corner of Escolar Road and Sturgeon Street.
Project Description:	This pond acts as the headwaters of the Sturgeon Street branch of the firehouse tributary of Devils Hole Creek. The outlet structure for the BMP ports water through a culvert under Escolar Road and into the stream channel. The outlet of this culvert has inadequate energy dissipation which has resulted in streambed scouring and stream-bank erosion in the stream channel immediately downstream of the outfall.
Stream or Subbasin:	Devils Hole Creek
Construction Requirements:	Utilize Naval Construction Battalion personnel and heavy equipment to install the energy dissipation material (quarry rock) into the stream channel for at least 50 m downstream.
Project Restrictions:	Temporarily cut outflow from BMP during construction.
Project Priority:	High (complete prior to next storm season)
Permit Requirements:	None
Long-Term Maintenance:	Periodic inspection and repair as required.
Estimated Project Cost:	$500 for material and one day of manpower and heavy equipment using CB and/or PW personnel.

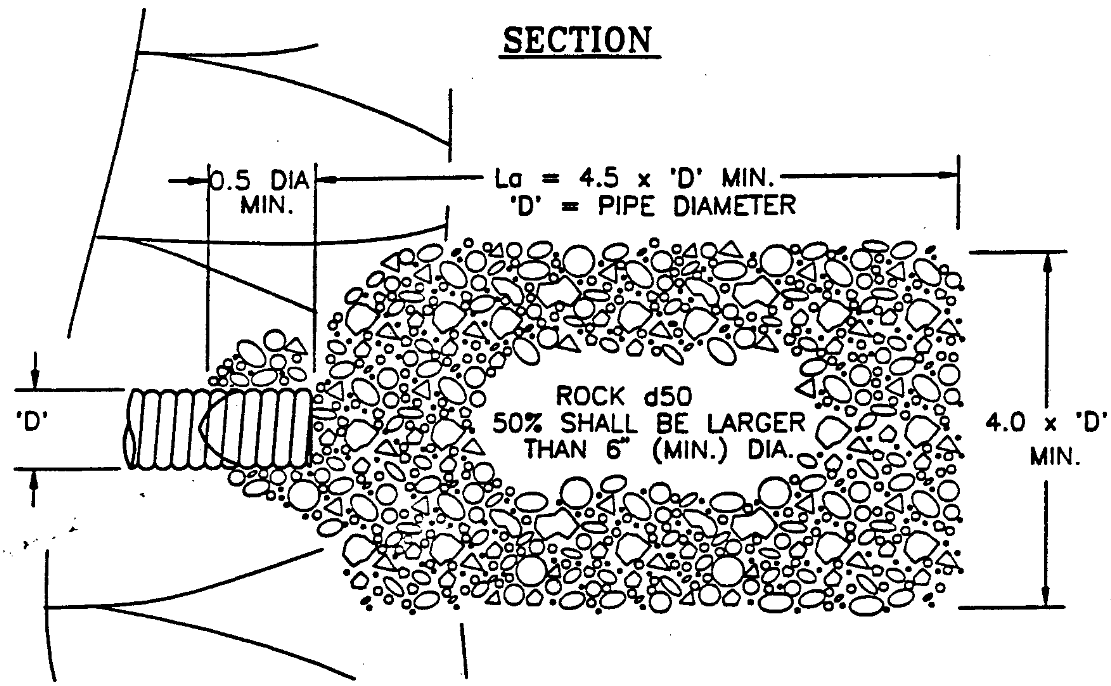
PROJECT DIAGRAM

(see next page)

ENERGY DISSIPATER



SECTION



PLAN

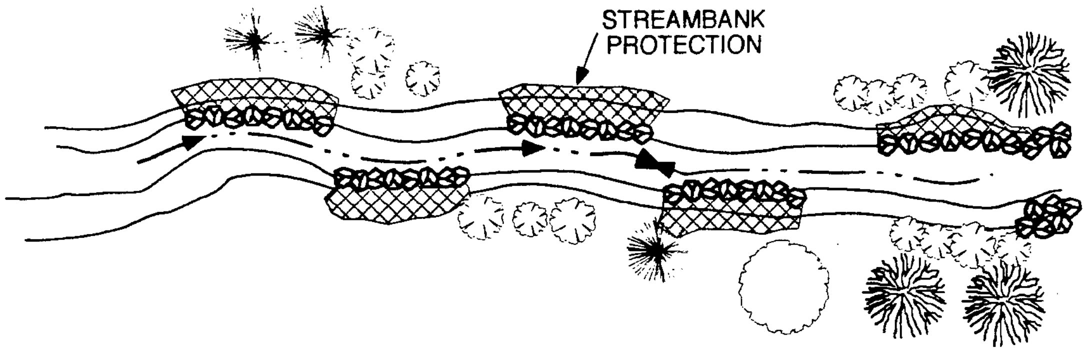
NOTES:

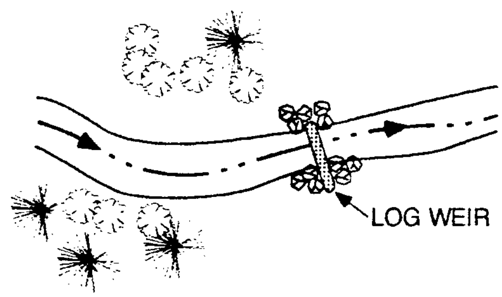
1. 'La' = LENGTH OF APRON. DISTANCE 'La' SHALL BE OF SUFFICIENT LENGTH TO DISSIPATE ENERGY.
2. APRON SHALL BE SET AT A ZERO GRADE AND ALIGNED STRAIGHT.
3. FILTER MATERIAL SHALL BE FILTER FABRIC OR 6" THICK (MIN.) GRADED GRAVEL LAYER.

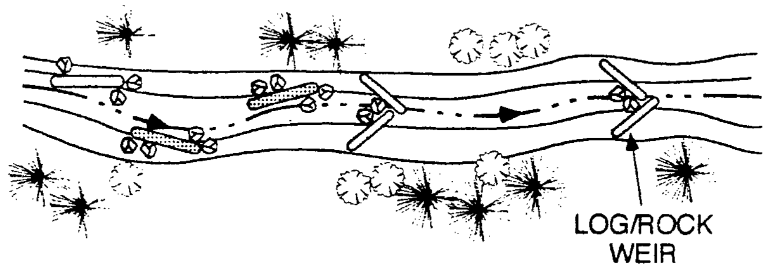
Project Location:	Sturgeon tributary of Devils Hole Creek; middle segment (upstream of Sturgeon Street crossing).
Project Description:	1. Improve in-stream flow conditions, provide stream-bank stabilization, and revegetate the riparian zone upstream of current "kiddie pond" near TRF Fire Station. 2. Replace current pond with a constructed wetland for stormwater quality treatment. This BMP, along with the Escolar Road R/D facility, would form a treatment-train system for managing most of the runoff from the SWFPAC industrial area and associated roads. Runoff currently routed to the TRF tributary of Devils Hole Creek via roadside conveyance should be rerouted down Escolar Road to the R/D facility. In this way, the Sturgeon tributary would be the primary path for stormwater and the TRF and Firehouse tributaries would be managed for salmonid habitat.
Stream or Subbasin:	Devils Hole Creek
Construction Requirements:	1. Utilize Naval Construction Battalion personnel and heavy equipment to reshape stream channel (~150 m) and stream banks and install stream-bank protection. Remove nonnative vegetation and replant with native riparian plants. Volunteers can be used to perform channel enhancements and planting after heavy equipment prep-work is complete. 2. Contract for design and construction of wetland treatment facility at the site of the current pond.
Project Restrictions:	Construction should be performed during summer, low-flow period (July–September). Flow diversion will be required.
Project Priority:	Low to moderate (within next 5 years).
Permit Requirements:	Joint Aquatic Resource (JARPA) Hydraulic Project Permit.
Long-Term Maintenance:	Periodic inspection and repair as required. Control invasive plants (blackberries and Scotch broom) until native vegetation dominates.
Estimated Project Cost:	1. $2,500 for material and one week of manpower and heavy equipment using CB and/or PW personnel for stream enhancements. 2. $25,000 for construction of stormwater-treatment facility.

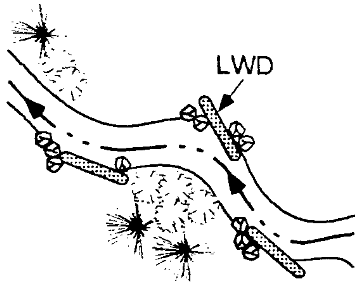
PROJECT DIAGRAM

(see next page)


STREAMBANK
PROTECTION


LOG WEIR

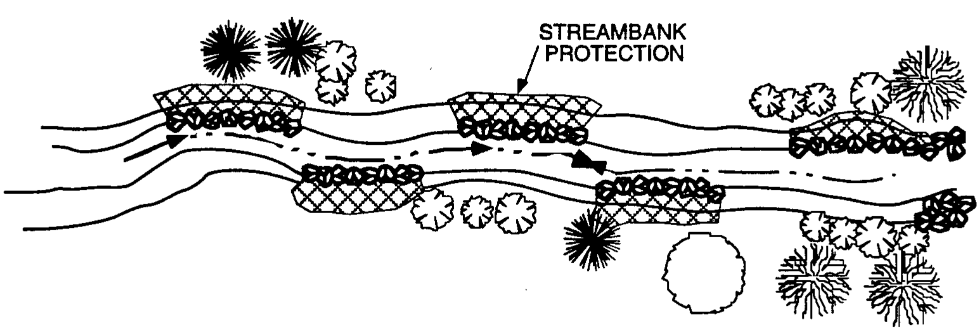

LOG/ROCK
WEIR


LWD

NSB BANGOR SWM PROJECT SUMMARY

Project Location:	Sturgeon tributary of Devils Hole Creek; lower segment (downstream of Sturgeon Street crossing).
Project Description:	1. Replace undersized culvert under Sturgeon Street with arched culvert to accommodate higher storm flows. 2. Improve in-stream flow conditions, provide stream-bank stabilization, and revegetate the riparian zone. 3. Improve stormwater conveyance along Sturgeon Street.
Stream or Subbasin:	Devils Hole Creek
Construction Requirements:	1. Utilize Naval Construction Battalion personnel and heavy equipment to remove existing culvert, install new culvert , and regrade roadbed. New arched culvert should be 2–3 feet in diameter to have sufficient capacity for estimated future stormwater flows. 2. Reshape stream channel (100 m) and stream banks and install stream-bank protection. Remove nonnative vegetation and replant with native riparian plants. Volunteers can be used to perform channel enhancements and planting after heavy equipment prep-work is complete. 3. Install energy dissipating check dams (rock) in roadside drainage swales along both sides of Sturgeon Street.
Project Restrictions:	Construction should be performed during summer, low-flow period (July–September). Flow diversion will be required.
Project Priority:	Low to moderate (within next 3 years).
Permit Requirements:	Joint Aquatic Resource (JARPA) Hydraulic Project Permit.
Long-Term Maintenance:	Periodic inspection. Control invasive plants (blackberries) until native vegetation dominates.
Estimated Project Cost:	$7,500 for material and one week of manpower and heavy equipment using CB and/or PW personnel.

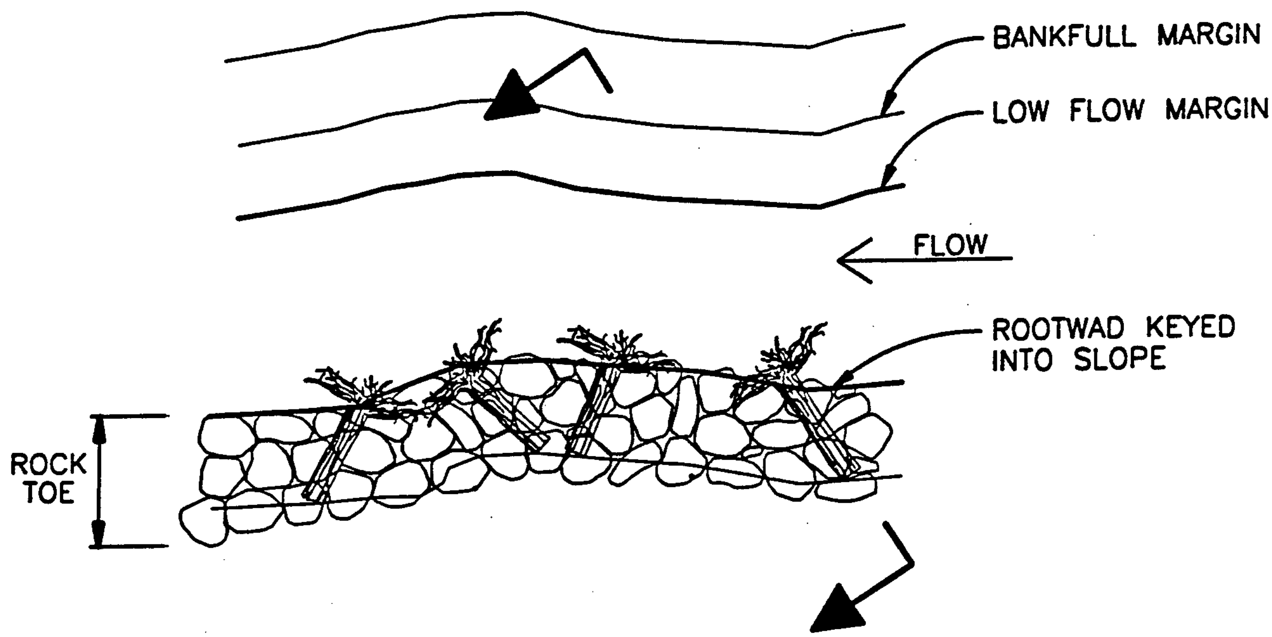
PROJECT DIAGRAM



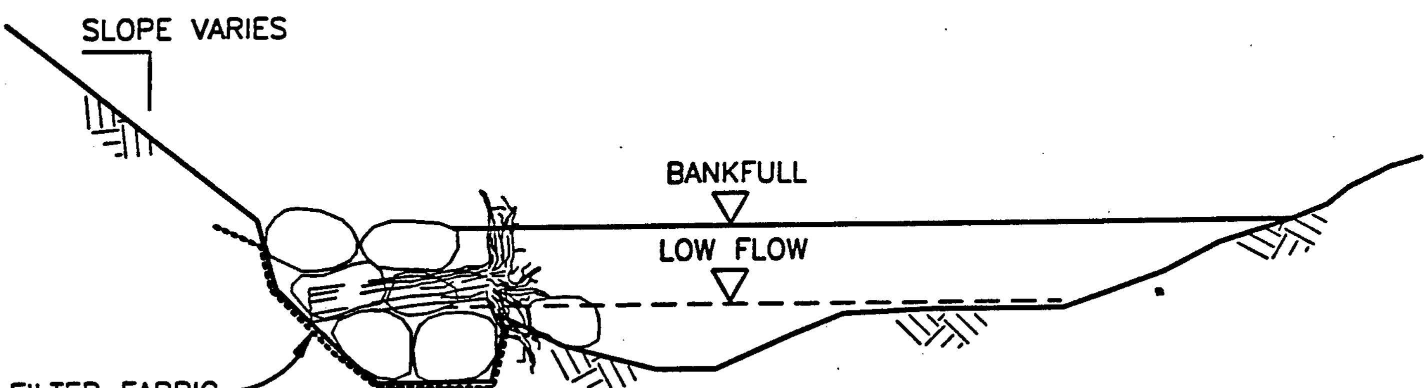
APPENDIX B

In-Stream Habitat Rehabilitation and Restoration Drawings

STREAM-BANK STABILIZATION

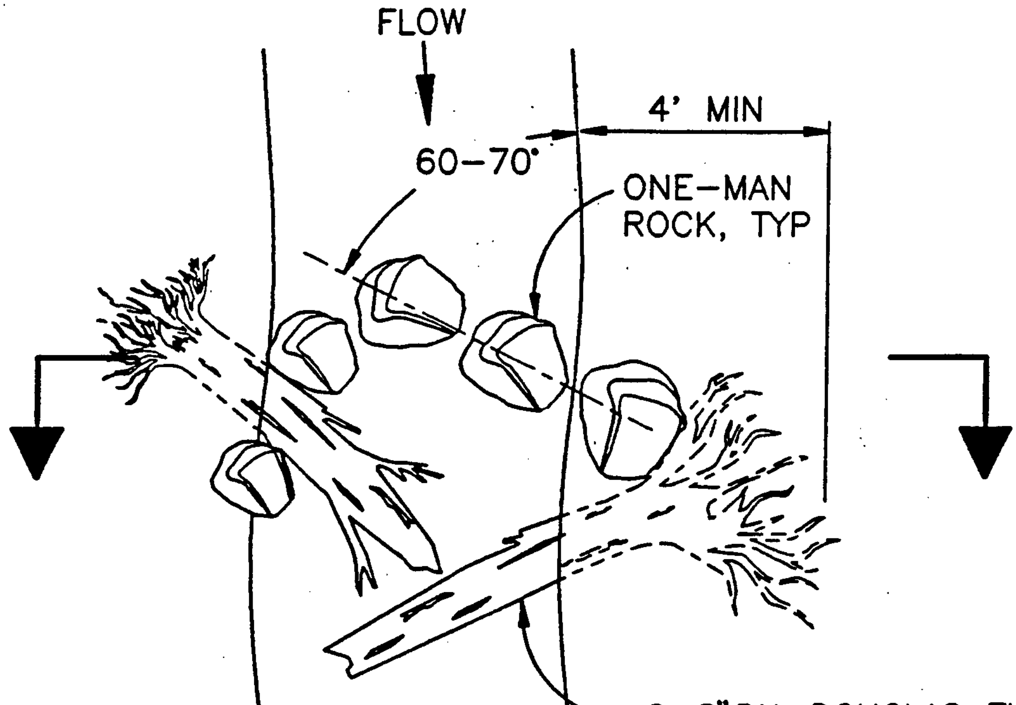


PLAN VIEW



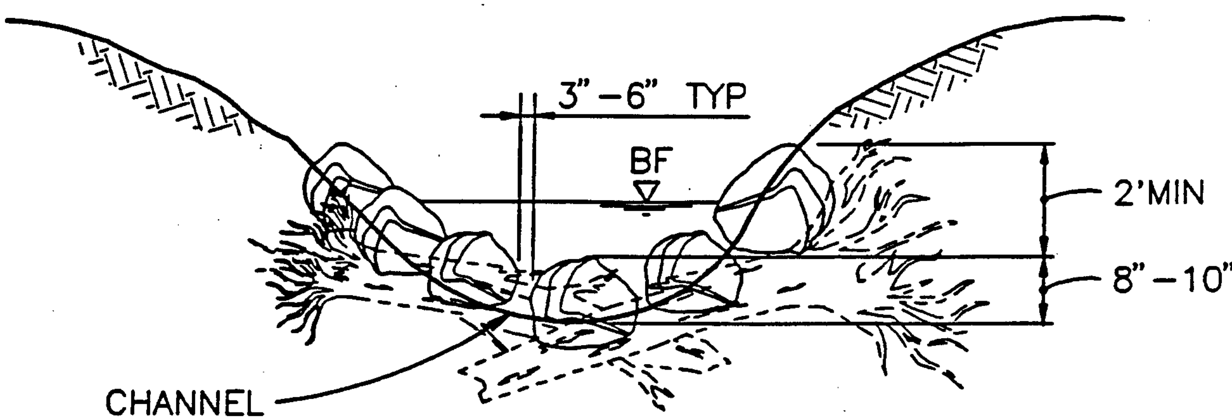
SECTION

IN-STREAM LARGE WOODY DEBRIS (LWD) INSTALLATION



PLAN

REVEGETATE DISTURBED
AREAS WITH STREAMBANK
SEED AND NATIVE PLANTS

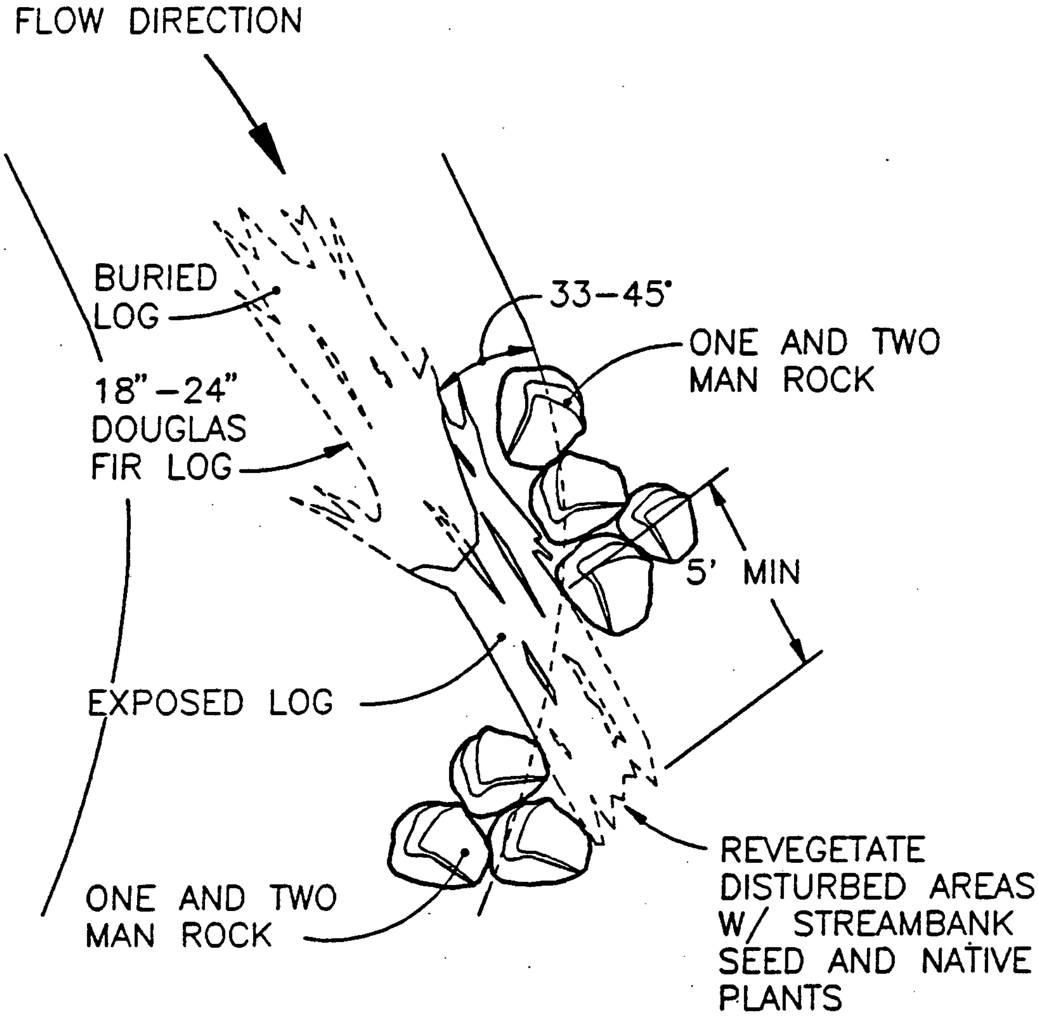


SECTION

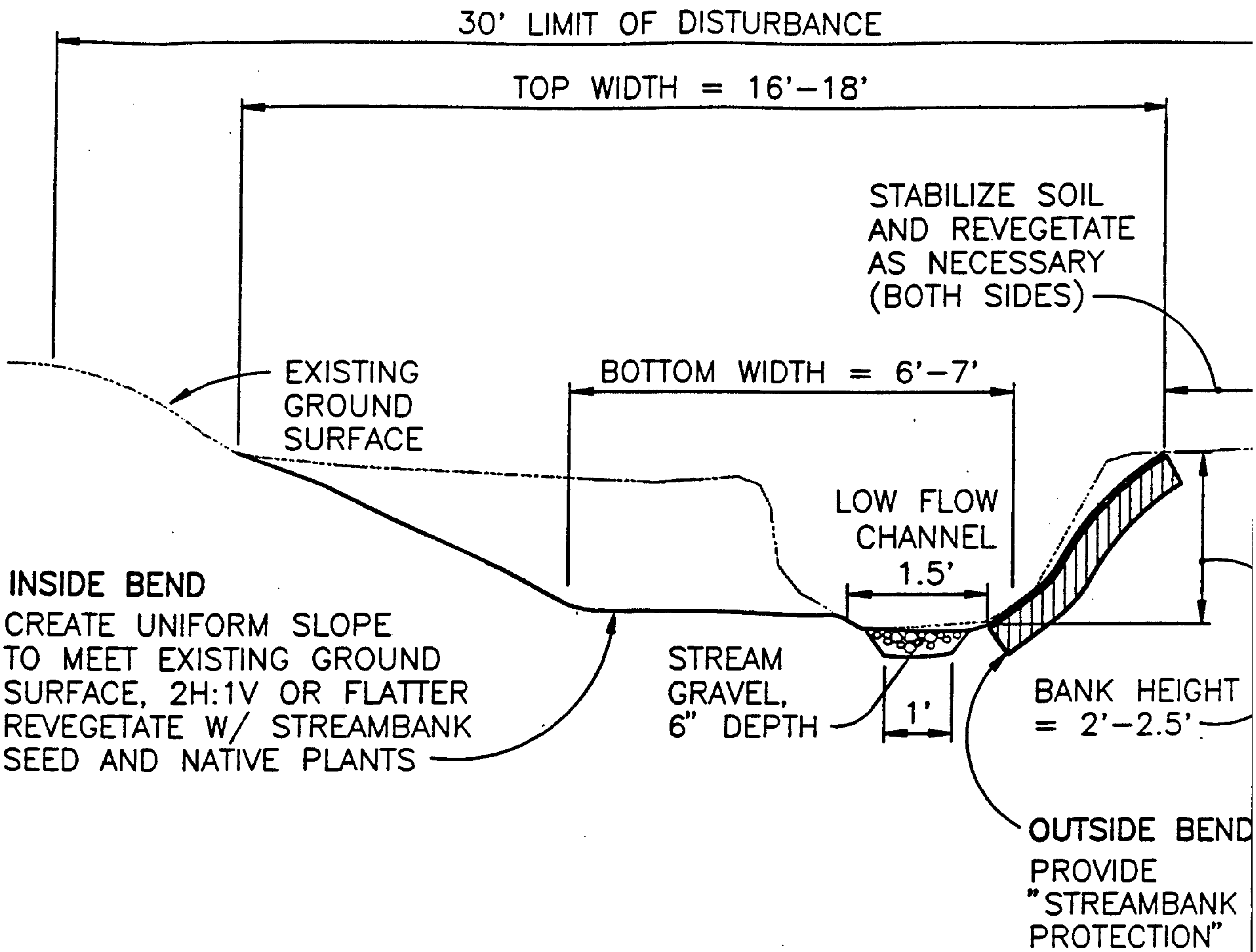
NOTE:

CONFIRM LOCATION AND PLACEMENT PRIOR TO INSTALLATION

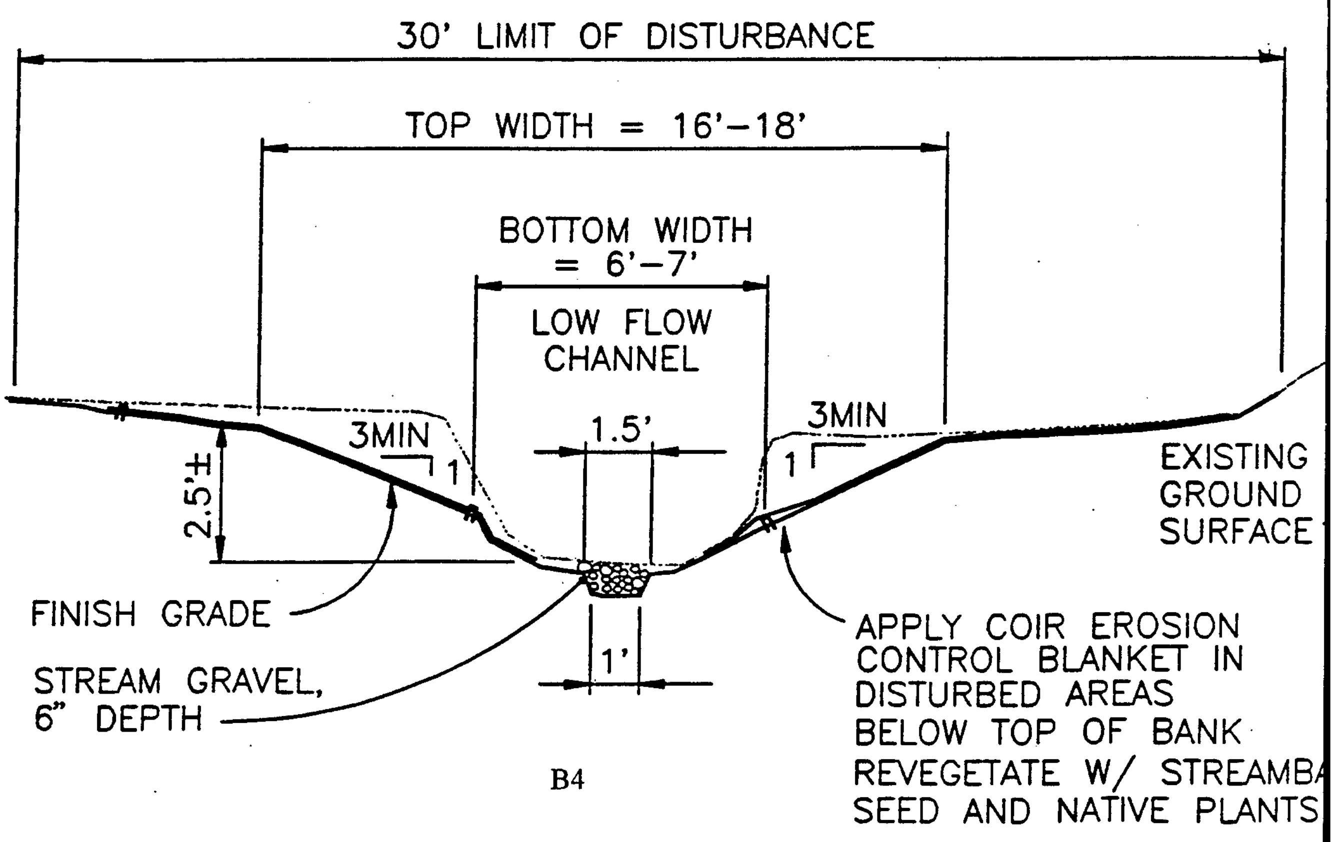
LOG DEFLECTOR



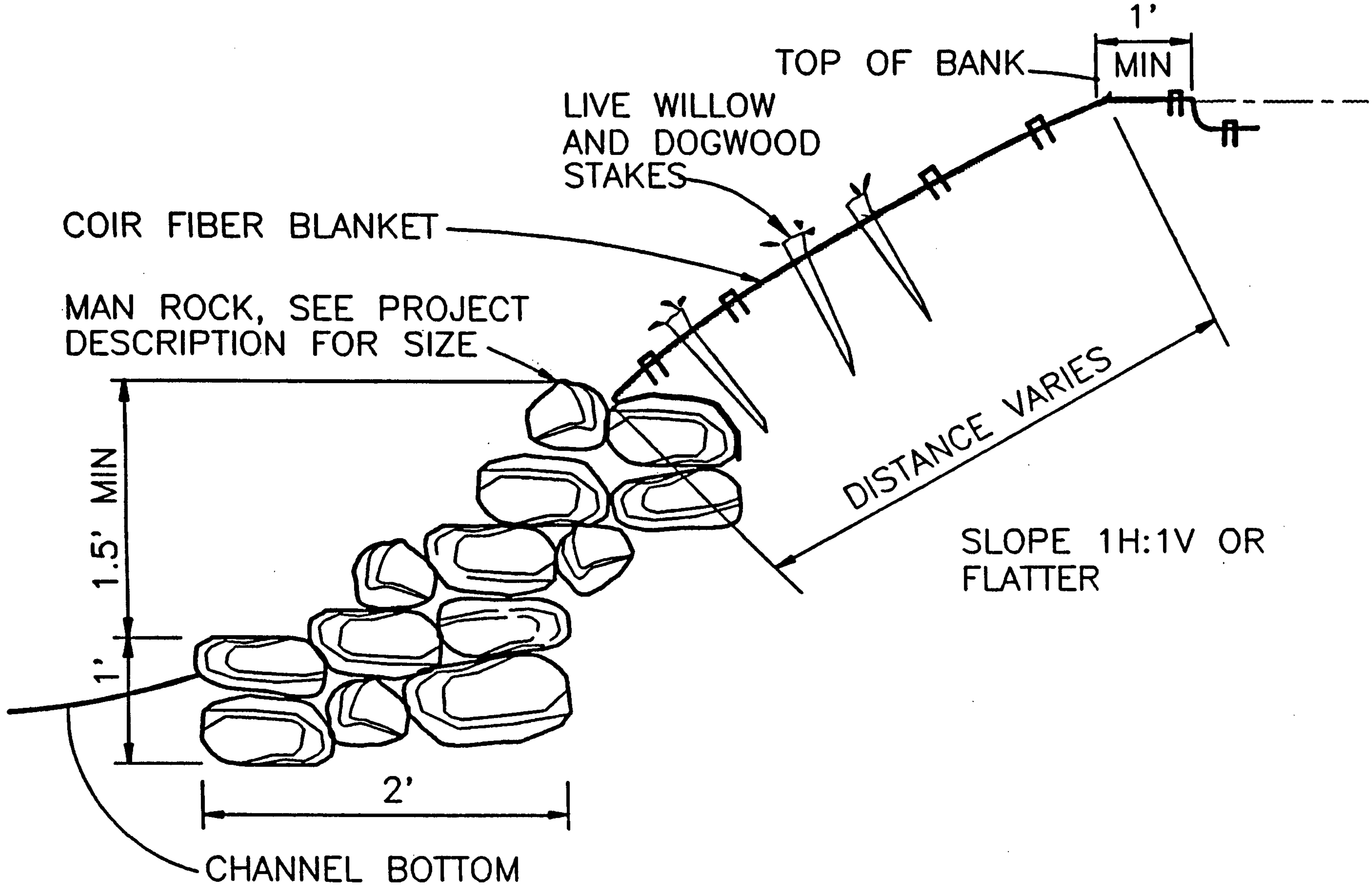
NOTE:
CONFIRM LOCATION AND PLACEMENT PRIOR TO INSTALLATION



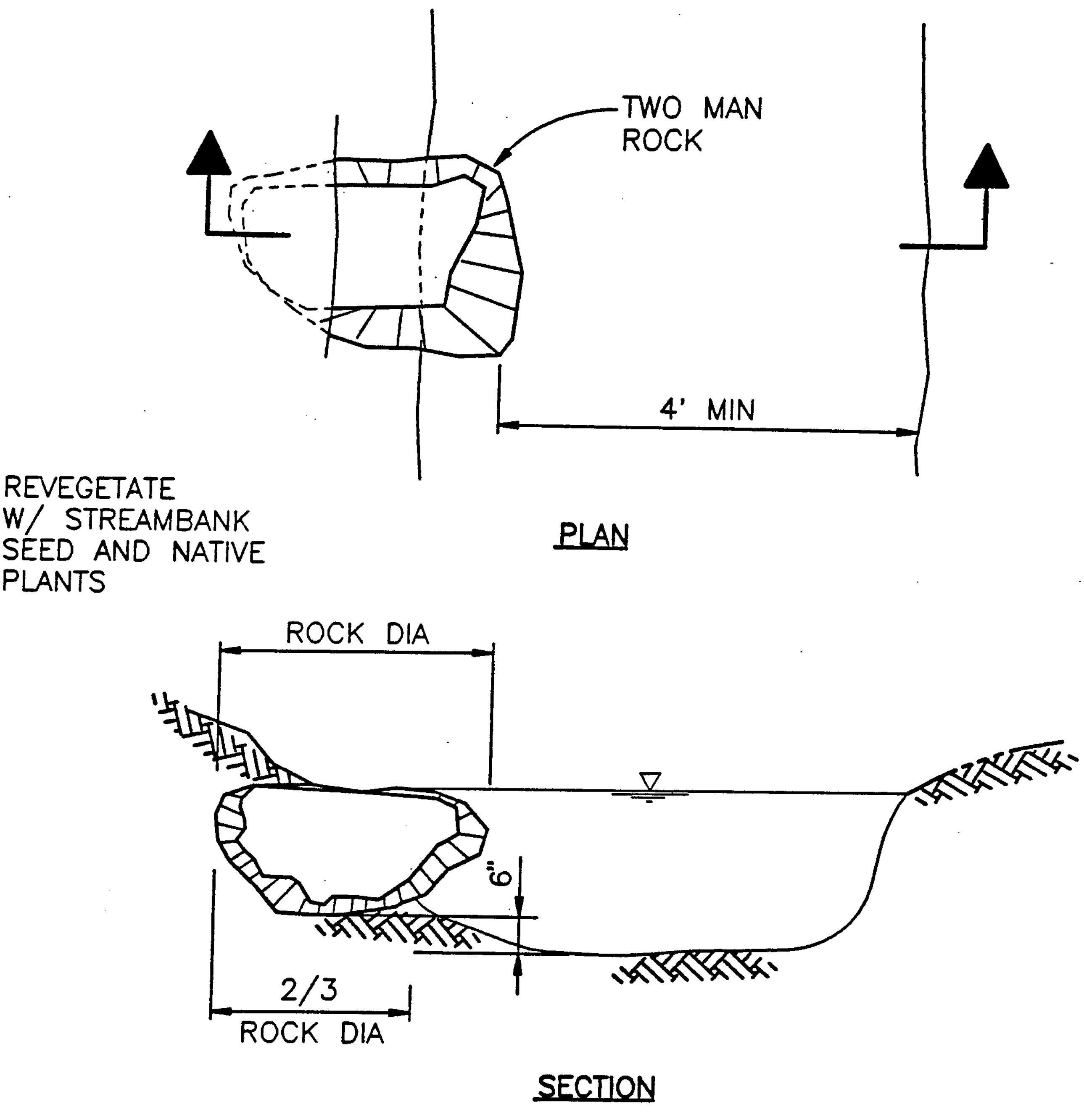
FLOODPLAIN RESTORATION



STREAM-BANK VEGETATIVE STABILIZATION



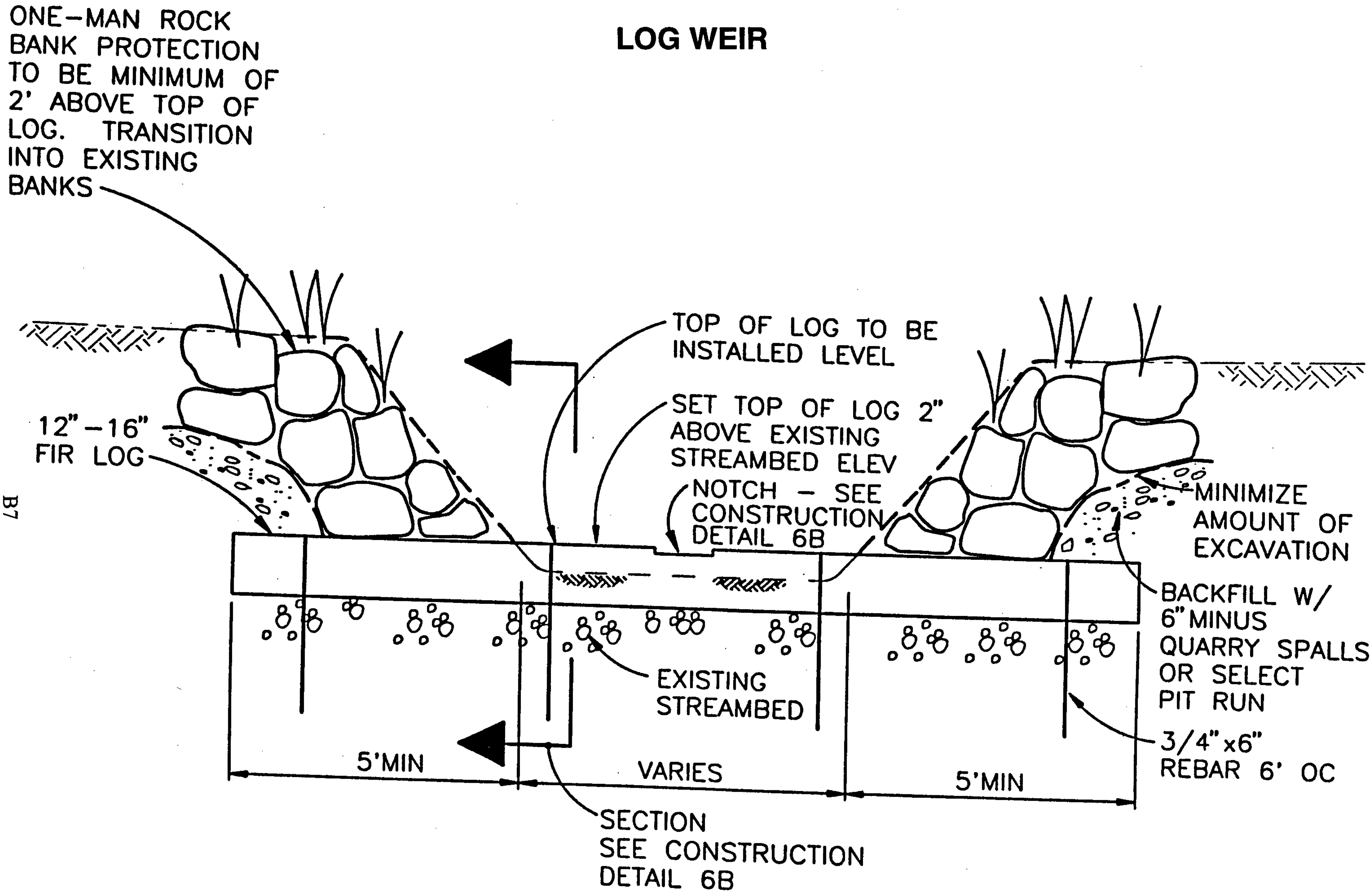
BOULDER INSTALLATION



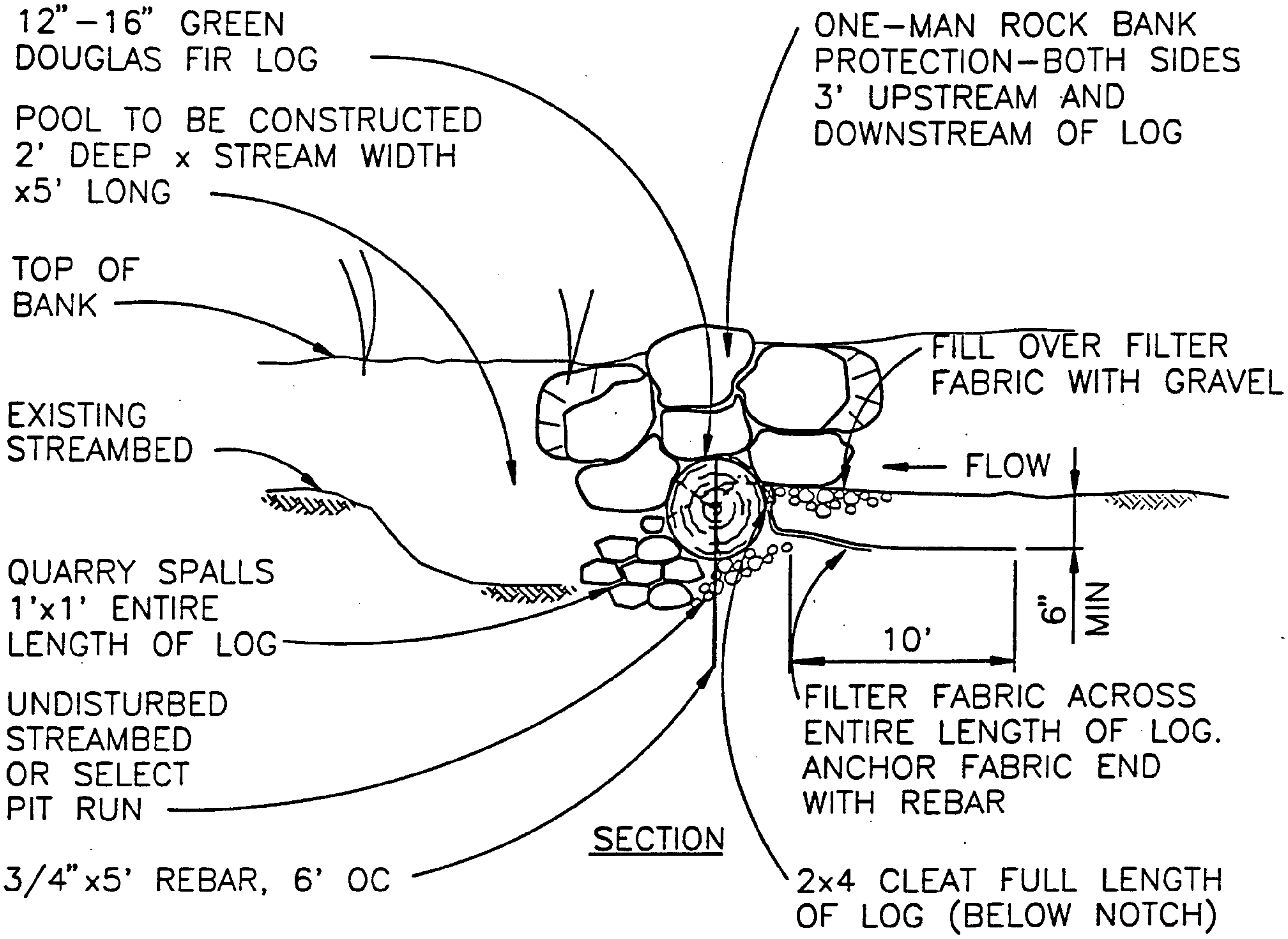
NOTE:

CONFIRM LOCATION AND PLACEMENT PRIOR TO INSTALLATION

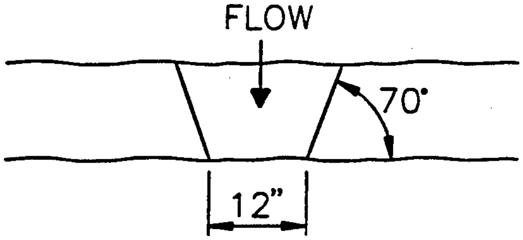
LOG WEIR


ONE-MAN ROCK BANK PROTECTION TO BE MINIMUM OF 2' ABOVE TOP OF LOG. TRANSITION INTO EXISTING BANKS
12"-16" FIR LOG
TOP OF LOG TO BE INSTALLED LEVEL
SET TOP OF LOG 2" ABOVE EXISTING STREAMBED ELEV
NOTCH - SEE CONSTRUCTION DETAIL 6B
MINIMIZE AMOUNT OF EXCAVATION
BACKFILL W/ 6" MINUS QUARRY SPALLS OR SELECT PIT RUN
EXISTING STREAMBED
3/4"x6" REBAR 6' OC
5'MIN
VARIES
5'MIN
SECTION SEE CONSTRUCTION DETAIL 6B

LOG WEIR



SECTION

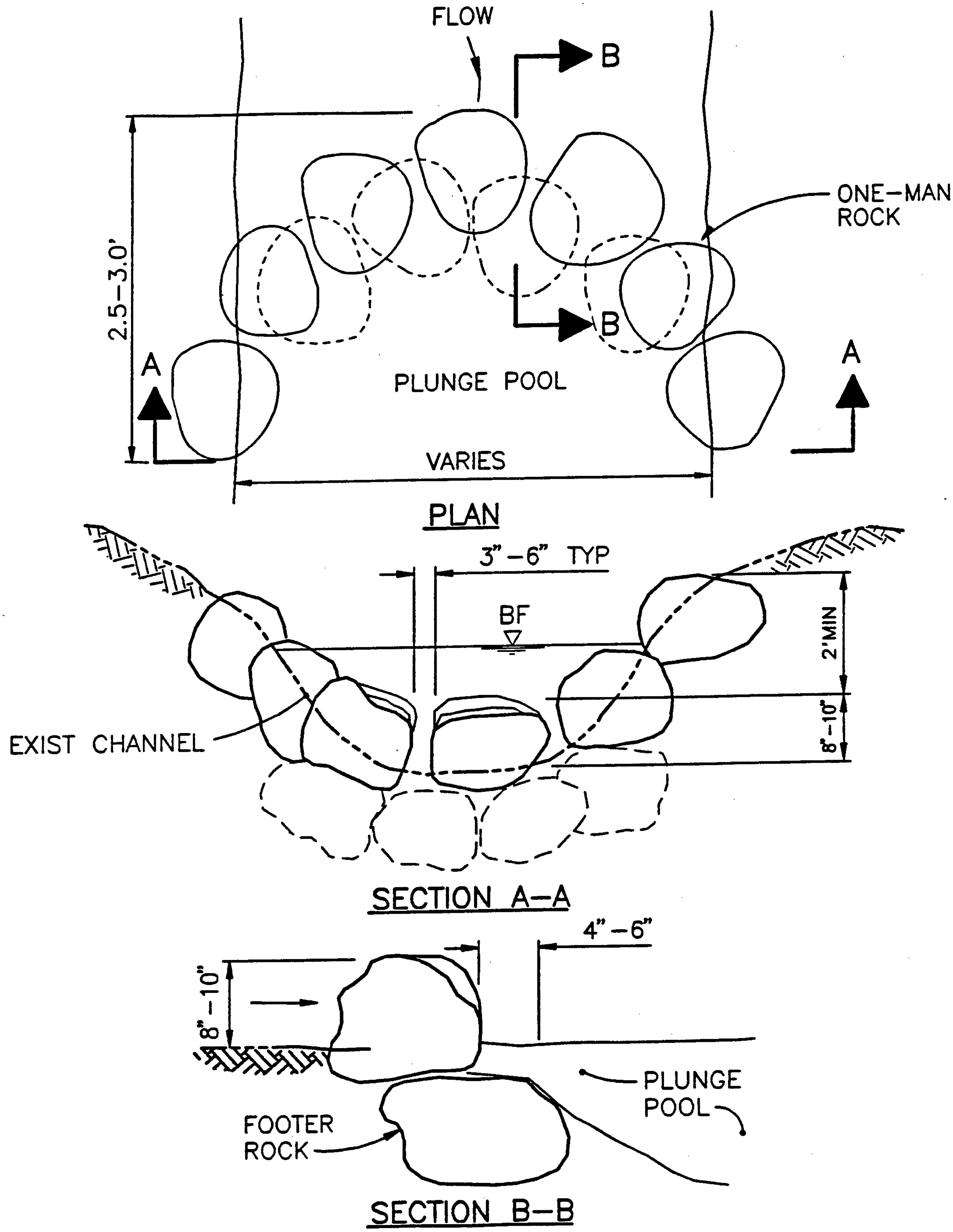


NOTCH DEPTH = 4"

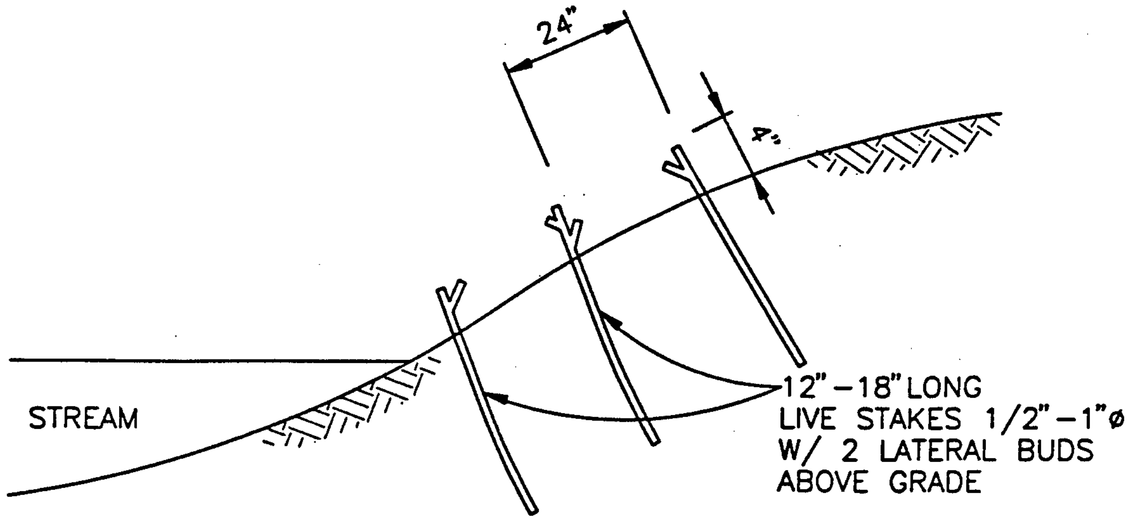
NOTCH DETAIL

NOTE:
CONFIRM LOCATION AND PLACEMENT PRIOR TO INSTALLATION

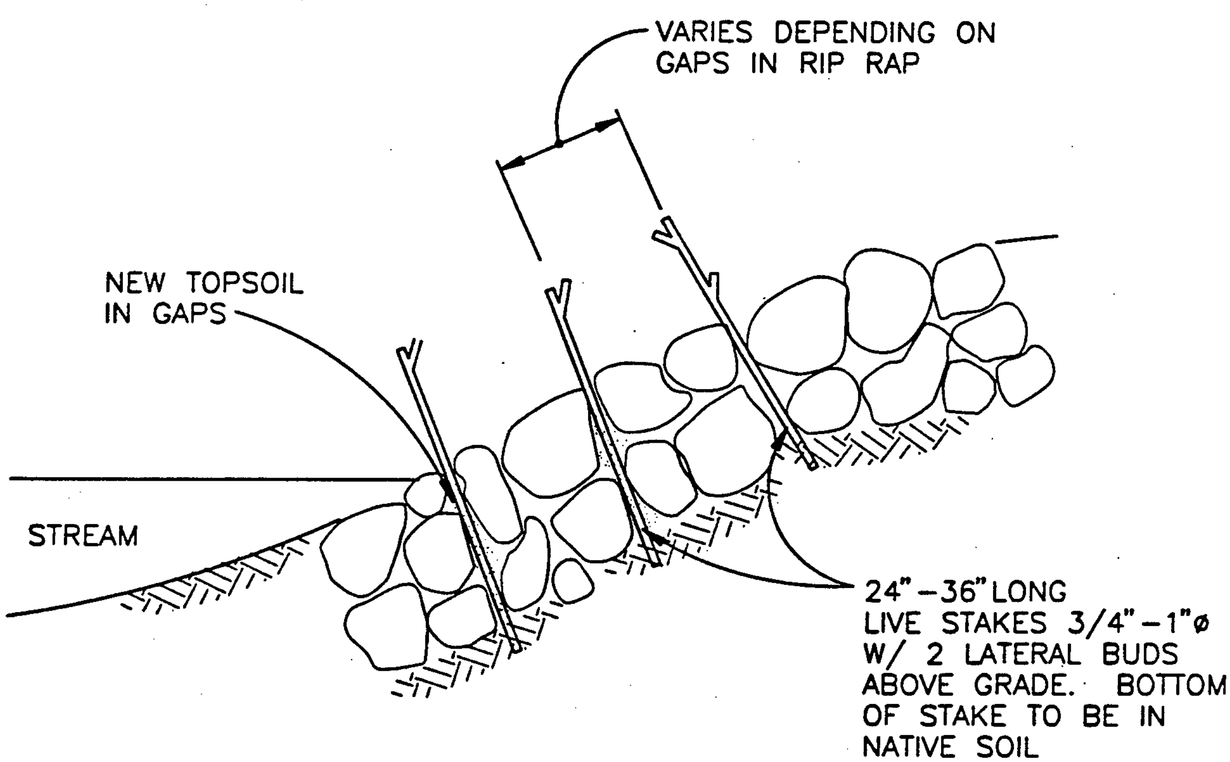
PLUNGE-POOL ROCK FORMATION



STREAM-BANK REVEGETATION

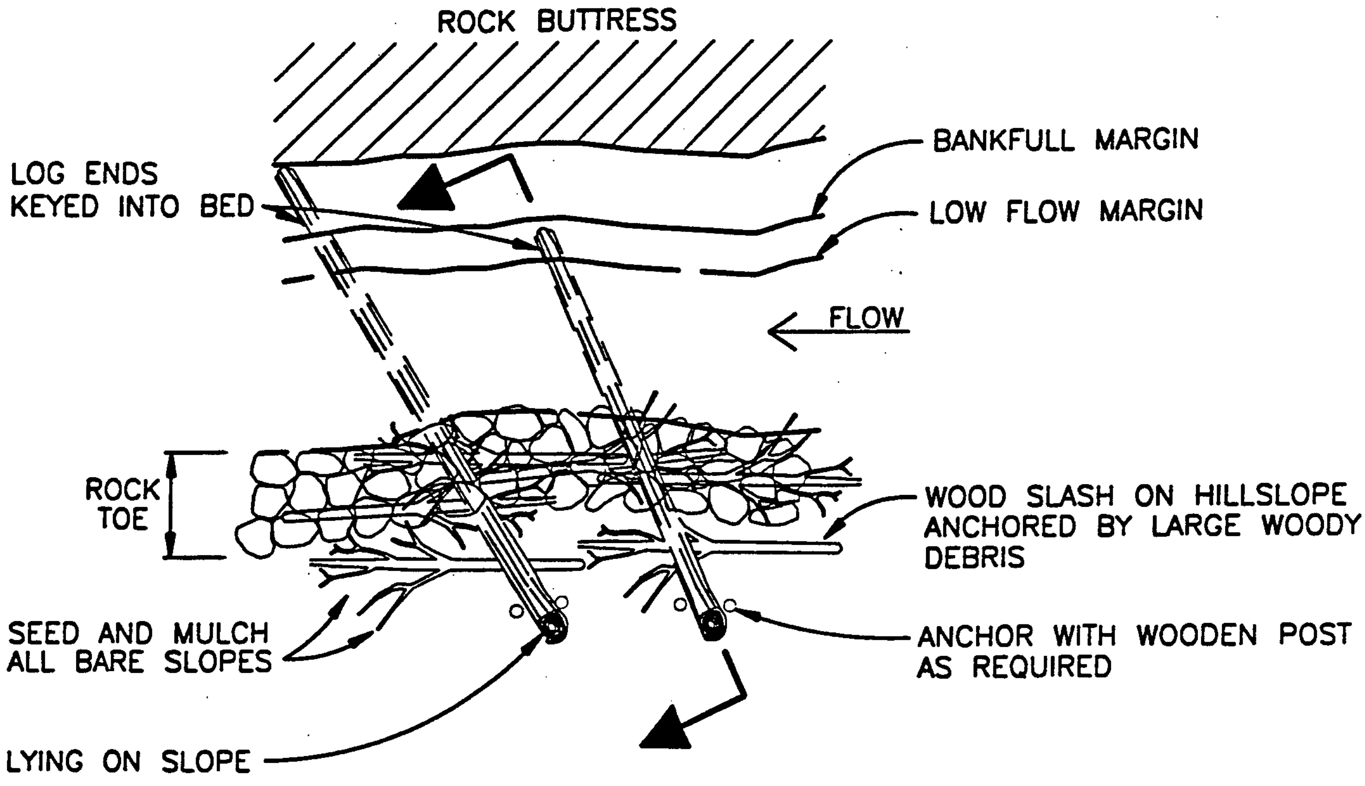


TYPICAL INSTALLATION

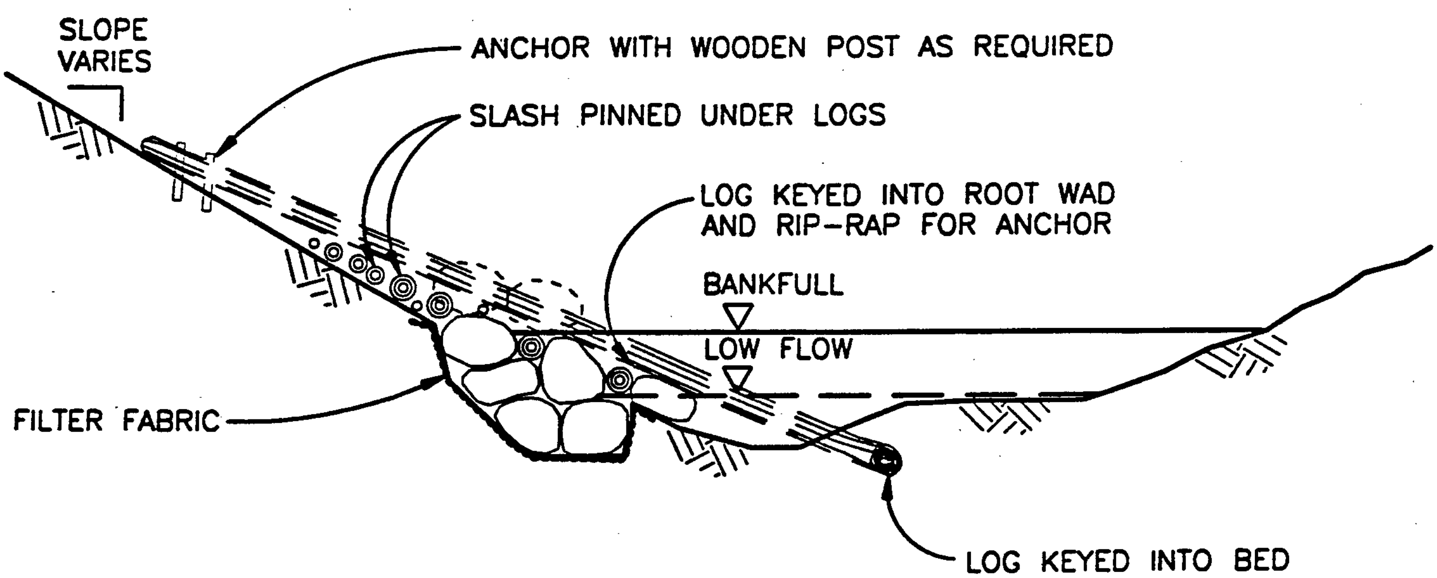


INSTALLATION IN RIPRAP

STREAM-BANK DEBRIS PROTECTION



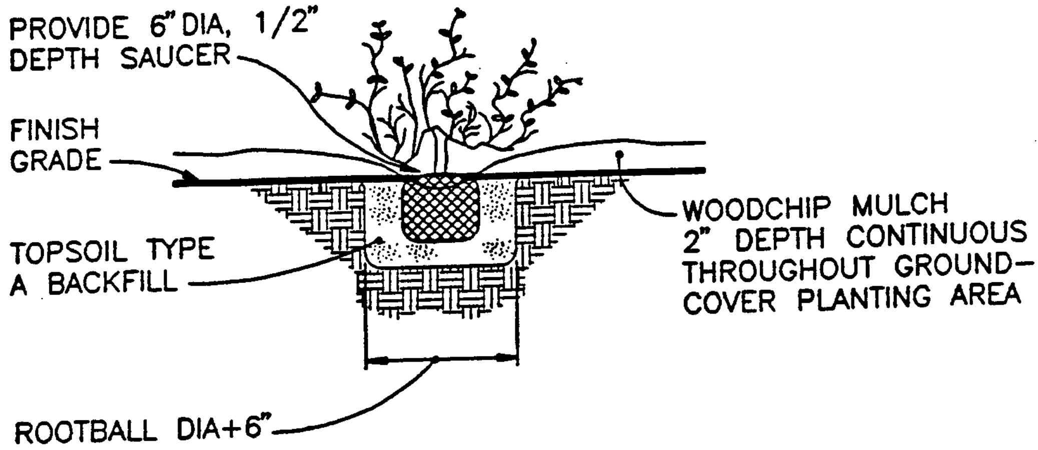
PLAN VIEW



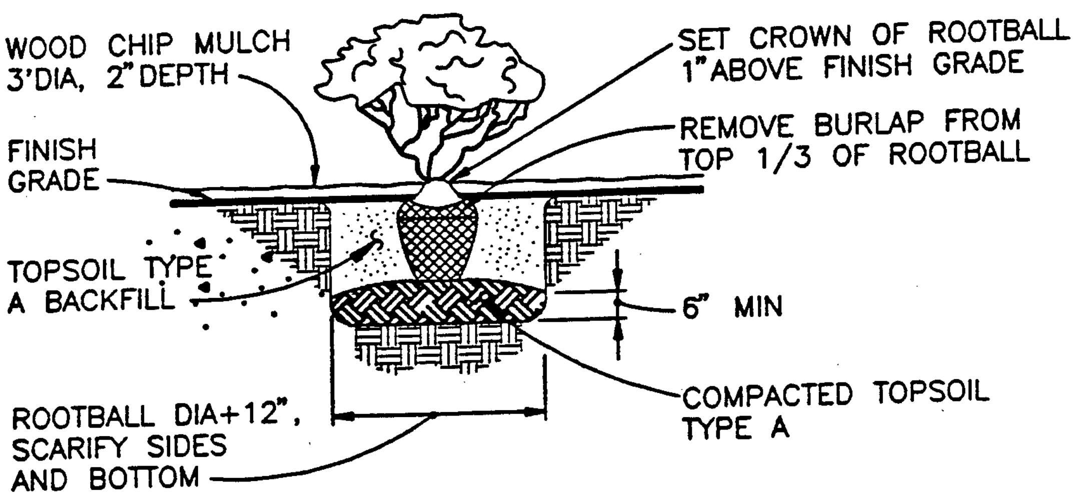
SECTION

SUGGESTED NATIVE PLANTS FOR RIPARIAN AREAS			
Common Name	Botanical Name	Size	Spacing
TREES			
Western Red Cedar	*Thuja plicata*	6-8′	18-20′ O.C.
Western Hemlock	*Tsuga heterophylla*	6-8′	18-20′ O.C.
Douglas Fir	*Pseudotsuga mensiesii*	6-8′	18-20′ O.C.
Black Cottonwood	*Populus trichocarpa*	8-10′	20′ O.C.
Bigleaf Maple	*Acer macrophyllum*	8-10′	20-22′ O.C.
Red Alder	*Alnus rubra*	6-8′	14-16′ O.C.
Paper Birch	*Betula papyrifera*	8-10′	10-12′ O.C.
Oregon Ash	*Fraxinus latifolia*	8-10′	14′ O.C.
Hazelnut	*Corylus cornuta*	4-6′	4-6′ O.C.
Vine Maple	*Acer circinatum*	4-5′	6-8′ O.C.
Willow	*Salix spp.*	slips	24″ O.C.
SHRUBS			
Red Elderberry	*Sambucus racemosa*	5 gal.	4′ O.C.
Red Osier Dogwood	*Cornus sericea*	5 gal.	4-6′ O.C.
Pacific Ninebark	*Physocarpos capitatus*	2 gal.	4-6′ O.C.
Indian Plum	*Oemlaria cerasiformus*	3 gal.	4′ O.C.
Red Flowering Currant	*Ribes sanguinium*	3 gal.	4′ O.C.
Cascade Oregon Grape	*Mahonia nervosa*	3 gal.	3′ O.C.
Salmonberry	*Rubus spectabilis*	3 gal.	4′ O.C.
Nutka Rose	*Rosa nutkana*	2 gal.	3′ O.C.
Snowberry	*Symphoricarpos albus*	3 gal.	3-4′ O.C.
Thimbleberry	*Rubus parviflorus*	5 gal.	3-4′ O.C.
Salal	*Gaultheria shallon*	3 gal.	3′ O.C.
PERENNIAL GROUNDCOVERS			
Sword Fern	*Polystichum munitum*	2 gal.	24-30″ O.C.
EMERGENTS AND AQUATICS			
Sedge	*Carex spp.*	root stock	24-30″ O.C.
Soft Rush	*Juncus effusus*	root stock	24-30″ O.C.
Small-Fruited Bulrush	*Scirpus microcarpus*	root stock	24-30″ O.C.
Burreed	*Sparganium emersum*	root stock	24-30″ O.C.

PLANTING INSTRUCTIONS

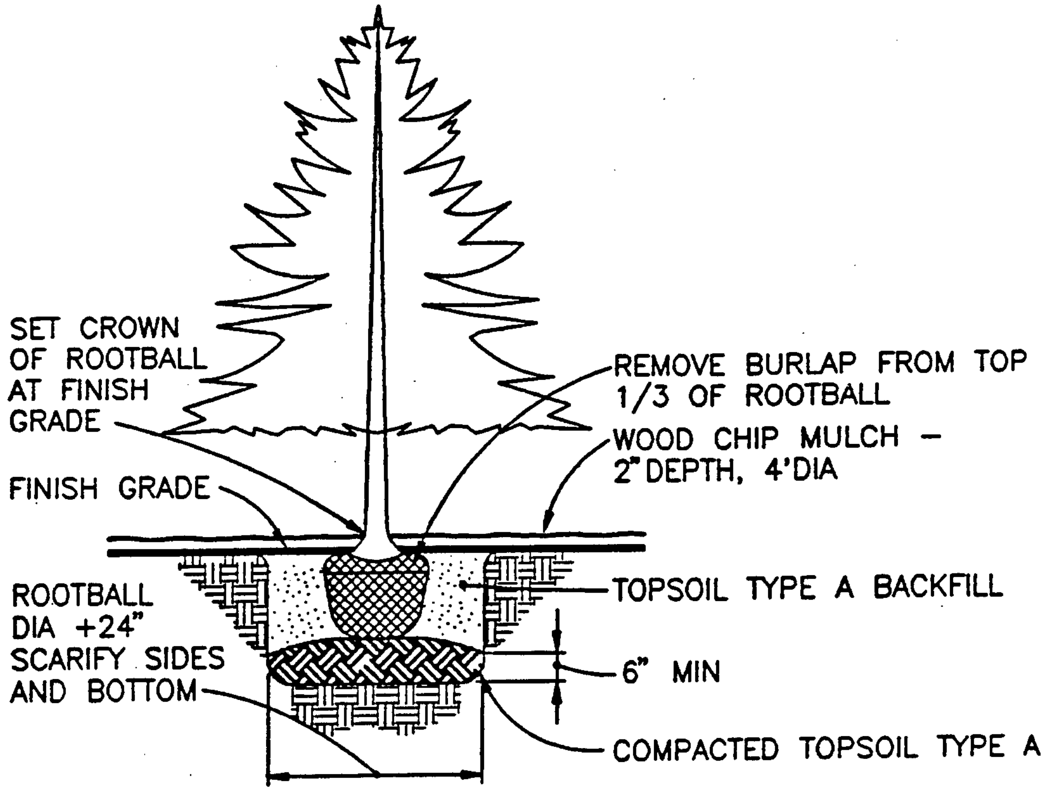


GROUNDCOVER

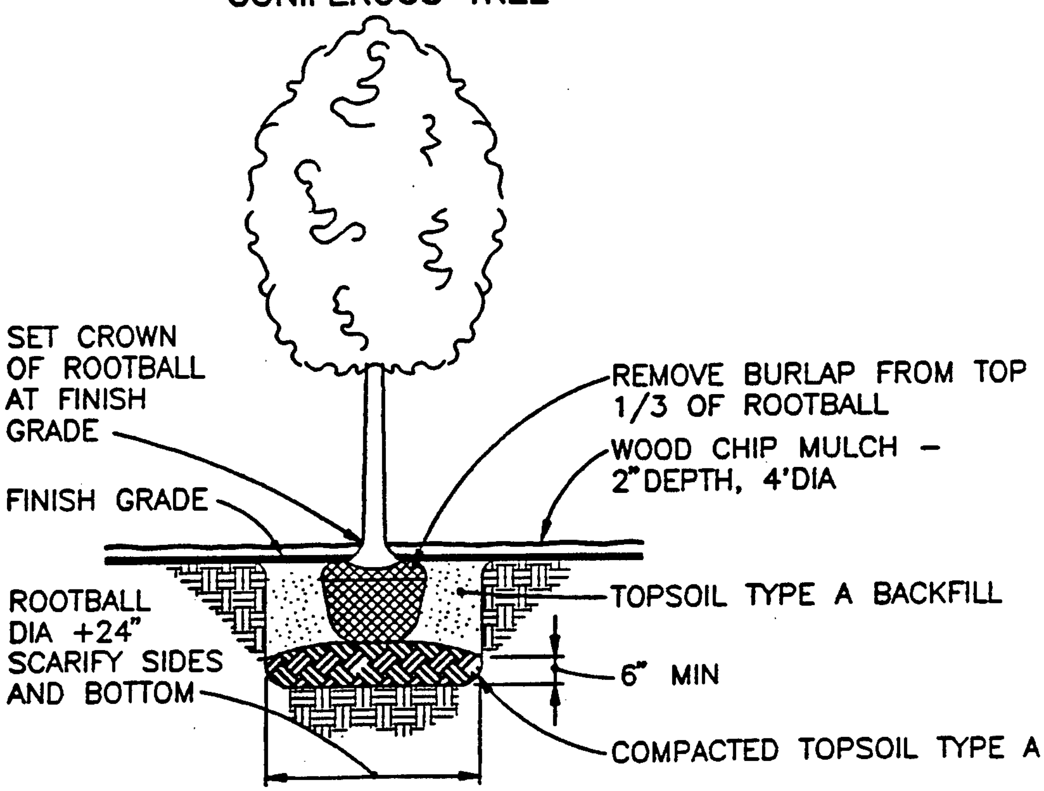


SHRUB

PLANTING INSTRUCTIONS



CONIFEROUS TREE



DECIDUOUS TREE

APPENDIX C

Riparian and In-Stream Habitat, Bangor Streams, 1997

STREAM		Sub-Basin	LENGTH	BUFFER	CANOPY	ROAD CROSSINGS			RIPARIAN CORRIDOR WIDTH (km)					RIPARIAN CORRIDOR WIDTH (%)					SEGMENT	CUMULATIVE UPSTREAM	
SUB-BASIN	STREAM SEGMENT	%TIA	(km)	QUALITY	COVER (%)	(#)	(#/km)	CUM	<10 m	10-30 m	30-50 m	50-100 m	>100m	<10 m	10-30 m	30-50 m	50-100 m	>100m	> 30m	%<10m	%>30m
Cattail	Lower/Mainstem	3.0	1.5	4	93	1	0.7	0.6	0.0	0.1	0.2	0.2	1.0	0.0%	6.7%	13.3%	13.3%	66.7%	93.3%	6.2	86.2
Cattail	Headwaters/North Fork	5.0	1.4	4	75	1	0.7	0.7	0.1	0.1	0.1	0.2	0.9	7.1%	7.1%	7.1%	14.3%	64.3%	85.7%	7.1	85.7
Cattail	Headwaters/Middle Fork	4.0	1.1	4	86	1	0.9	0.9	0.1	0.1	0.1	0.2	0.6	9.1%	9.1%	9.1%	18.2%	54.5%	81.8%	9.1	81.8
Cattail	Headwaters/South Fork	8.0	2.5	4	83	1	0.4	0.4	0.2	0.2	0.3	0.3	1.5	8.0%	8.0%	12.0%	12.0%	60.0%	84.0%	8.0	84.0
Devils Hole	Lower/Mainstem	10.0	1.2	4	96	1	0.8	2.2	0.1	0.0	0.1	0.0	1.0	8.3%	0.0%	8.3%	0.0%	83.3%	91.7%	15.2	73.4
Devils Hole	Lower TRF Tributary	15.0	0.3	4	92	1	3.3	3.0	0.0	0.0	0.0	0.0	0.3	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	15.0	75.0
Devils Hole	Middle TRF Tributary	35.0	0.5	1	22	4	8.0	2.9	0.3	0.1	0.1	0.0	0.0	60.0%	20.0%	20.0%	0.0%	0.0%	20.0%	17.6	70.6
Devils Hole	Upper TRF Tributary	15.0	1.2	3	84	1	0.8	0.8	0.0	0.1	0.1	0.2	0.8	0.0%	8.3%	8.3%	16.7%	66.7%	91.7%	0.0	91.7
Devils Hole	Lower Firehouse Tributary	20.0	0.2	3	88	1	5.0	2.7	0.1	0.1	0.0	0.0	0.0	50.0%	50.0%	0.0%	0.0%	0.0%	0.0%	13.3	73.3
Devils Hole	Middle Firehouse Tributary	15.0	0.3	2	35	2	6.7	2.3	0.1	0.0	0.2	0.0	0.0	33.3%	0.0%	66.7%	0.0%	0.0%	66.7%	7.7	84.6
Devils Hole	Upper Firehouse Tributary	12.0	1.0	3	78	1	1.0	1.0	0.0	0.1	0.0	0.2	0.7	0.0%	10.0%	0.0%	20.0%	70.0%	90.0%	0.0	90.0
Devils Hole	Lower SWFPAC Tributary	10.0	0.4	4	90	1	2.5	1.8	0.1	0.0	0.0	0.0	0.3	25.0%	0.0%	0.0%	0.0%	75.0%	75.0%	17.6	64.7
Devils Hole	Middle SWFPAC Tributary	10.0	0.3	3	87	1	3.3	1.5	0.1	0.0	0.0	0.1	0.1	33.3%	0.0%	0.0%	33.3%	33.3%	66.7%	15.4	61.5
Devils Hole	Upper SWFPAC Tributary	15.0	1.0	4	73	1	1.0	1.0	0.1	0.3	0.1	0.1	0.4	10.0%	30.0%	10.0%	10.0%	40.0%	60.0%	10.0	60.0
Devils Hole	Lower Sturgeon Road Tributary	10.0	0.5	2	50	2	4.0	2.0	0.2	0.1	0.0	0.1	0.1	40.0%	20.0%	0.0%	20.0%	20.0%	40.0%	20.0	66.7
Devils Hole	Middle Sturgeon Road Tributary	15.0	0.6	3	75	0	0.0	1.0	0.0	0.1	0.1	0.1	0.3	0.0%	16.7%	16.7%	16.7%	50.0%	83.3%	10.0	80.0
Devils Hole	Upper Sturgeon Road Tributary	25.0	0.4	2	65	1	2.5	2.5	0.1	0.0	0.1	0.1	0.1	25.0%	0.0%	25.0%	25.0%	25.0%	75.0%	25.0	75.0
Clear	Headwaters/North Fork	30.0	0.6	1	15	3	5.0	5.0	0.2	0.2	0.2	0.0	0.0	33.3%	33.3%	33.3%	0.0%	0.0%	33.3%	33.3	33.3
Clear	North Fork/Mainstem	20.0	1.0	3	75	2	2.0	3.1	0.1	0.1	0.2	0.2	0.4	10.0%	10.0%	20.0%	20.0%	40.0%	80.0%	18.8	62.5
Clear	Headwaters/Middle Fork	30.0	1.2	1	20	3	2.5	2.5	0.4	0.4	0.4	0.0	0.0	33.3%	33.3%	33.3%	0.0%	0.0%	33.3%	33.3	33.3
Clear	Middle Fork/Mainstem	15.0	1.1	3	80	3	2.7	2.6	0.1	0.2	0.3	0.2	0.3	9.1%	18.2%	27.3%	18.2%	27.3%	72.7%	21.7	45.3
Clear	Headwaters/South Fork	20.0	1.2	2	25	4	3.3	3.3	0.2	0.4	0.6	0.0	0.0	16.7%	33.3%	50.0%	0.0%	0.0%	50.0%	16.7	50.0
Clear	South Fork/Mainstem	15.0	1.3	3	85	2	1.5	2.4	0.1	0.2	0.4	0.2	0.4	7.7%	15.4%	30.8%	15.4%	30.8%	76.9%	12.0	64.0
Clear	Lower West Branch	15.0	2.0	1	69	3	1.5	2.0	0.5	0.5	0.4	0.2	0.1	25.0%	25.0%	20.0%	10.0%	5.0%	35.0%	17.8	51.1
Clear	Lower East Branch	20.0	2.5	2	44	5	2.0	2.8	1.0	0.8	0.3	0.2	0.2	40.0%	32.0%	12.0%	8.0%	8.0%	28.0%	20.5	56.4
Clear	Lower Mainstem/Silverdale	30.0	0.5	2	50	3	6.0	2.5	0.3	0.1	0.1	0.0	0.0	60.0%	20.0%	20.0%	0.0%	0.0%	20.0%	25.4	46.5

DOMINANT LAND-COVER WITHIN THE RIPARIAN CORRIDOR (km)							DOMINANT LAND-COVER WITHIN THE RIPARIAN CORRIDOR (%)							SEG	CUM	DOMINANT
FOREST(OG)	FOREST(M)	FOREST(Y)	WETLAND	RURAL	SUBURBAN	URBAN	FOREST(OG)	FOREST(M)	FOREST(Y)	WETLAND	RURAL	SUBURBAN	URBAN	%NAT'L	%NAT'L	RIPARIAN VEGETATION
0.0	1.0	0.1	0.4	0.0	0.0	0.0	0.0%	66.7%	6.7%	26.7%	0.0%	0.0%	0.0%	100.0	77.8	Mature-Coniferous
0.0	1.0	0.2	0.0	0.2	0.0	0.0	0.0%	71.4%	14.3%	0.0%	14.3%	0.0%	0.0%	85.7	87.0	Mature-Coniferous
0.0	1.0	0.1	0.0	0.0	0.0	0.0	0.0%	90.9%	9.1%	0.0%	0.0%	0.0%	0.0%	100.0	88.0	Mature-Coniferous
0.0	2.0	0.1	0.0	0.5	0.0	0.0	0.0%	80.0%	4.0%	0.0%	20.0%	0.0%	0.0%	84.0	84.0	Mature-Coniferous
0.0	0.8	0.1	0.3	0.0	0.0	0.0	0.0%	66.7%	8.3%	25.0%	0.0%	0.0%	0.0%	100.0	86.8	Mature-Coniferous
0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0	80.0	Mature-Coniferous
0.0	0.0	0.1	0.1	0.0	0.0	0.3	0.0%	0.0%	20.0%	20.0%	0.0%	0.0%	60.0%	40.0	76.5	Young-Deciduous
0.0	0.4	0.3	0.4	0.0	0.0	0.1	0.0%	33.3%	25.0%	33.3%	0.0%	0.0%	8.3%	91.7	91.7	Mature-Mixed
0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0%	50.0%	50.0%	0.0%	0.0%	0.0%	0.0%	100.0	81.7	Mature-Coniferous
0.0	0.0	0.2	0.0	0.0	0.0	0.1	0.0%	0.0%	66.7%	0.0%	0.0%	0.0%	33.3%	66.7	64.6	Young-Deciduous
0.0	0.5	0.3	0.1	0.0	0.0	0.1	0.0%	50.0%	30.0%	10.0%	0.0%	0.0%	10.0%	90.0	90.0	Mature-Mixed
0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0	94.1	Mature-Coniferous
0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0%	66.7%	33.3%	0.0%	0.0%	0.0%	0.0%	100.0	92.3	Mature-Coniferous
0.0	0.3	0.1	0.5	0.0	0.0	0.1	0.0%	30.0%	10.0%	50.0%	0.0%	0.0%	10.0%	90.0	90.0	Wetland
0.0	0.1	0.1	0.0	0.2	0.0	0.1	0.0%	20.0%	20.0%	0.0%	40.0%	0.0%	20.0%	40.0	66.7	Young-Deciduous
0.0	0.1	0.4	0.0	0.1	0.0	0.0	0.0%	16.7%	66.7%	0.0%	16.7%	0.0%	0.0%	83.3	80.0	Young-Mixed
0.0	0.1	0.2	0.0	0.1	0.0	0.0	0.0%	25.0%	50.0%	0.0%	25.0%	0.0%	0.0%	75.0	75.0	Young-Mixed
0.0	0.0	0.2	0.0	0.4	0.0	0.0	0.0%	0.0%	33.3%	0.0%	66.7%	0.0%	0.0%	33.3	33.3	Young-Deciduous
0.0	0.4	0.4	0.0	0.2	0.0	0.0	0.0%	40.0%	40.0%	0.0%	20.0%	0.0%	0.0%	80.0	62.5	Mature-Mixed
0.0	0.0	0.4	0.2	0.4	0.2	0.0	0.0%	0.0%	33.3%	16.7%	33.3%	16.7%	0.0%	50.0	50.0	Wetland
0.0	0.6	0.2	0.0	0.2	0.1	0.0	0.0%	54.5%	18.2%	0.0%	18.2%	9.1%	0.0%	72.7	60.0	Mature-Coniferous
0.0	0.4	0.4	0.4	0.0	0.0	0.0	0.0%	33.3%	33.3%	33.3%	0.0%	0.0%	0.0%	100.0	100.0	Young-Deciduous
0.0	0.5	0.4	0.0	0.2	0.2	0.0	0.0%	38.5%	30.8%	0.0%	15.4%	15.4%	0.0%	69.2	84.0	Mature-Mixed
0.0	0.0	1.0	0.1	0.5	0.4	0.0	0.0%	0.0%	50.0%	5.0%	25.0%	20.0%	0.0%	55.0	73.1	Young-Deciduous
0.0	0.2	0.7	0.1	1.0	0.5	0.0	0.0%	8.0%	28.0%	4.0%	40.0%	20.0%	0.0%	40.0	61.5	Young-Deciduous
0.0	0.0	0.2	0.0	0.2	0.1	0.0	0.0%	0.0%	40.0%	0.0%	40.0%	20.0%	0.0%	40.0	59.0	Young-Deciduous

Habitat Data

Stream Sub-Basin	Stream Segment Location/Description	Upstream %TIA	Road-Density (km/km^2)	Basin Area (km^2)	Stream Gradient	Valley (%) Side-Slope	BFW (m)	BFD (m)	FPW (m)	BFW/BFD Ratio	FPW/BFW Ratio	Channel Confinement	Channel Sinuosity
Cattail	Lower/Mainstem	3.0	1.8	1.0	1.2%	25.0	5.0	0.3	11.0	16.7	2.2	Unconfined	High
Cattail	Headwaters/North Fork	5.0	1.9	1.0	5.2%	15.5	4.0	0.3	5.5	16.0	1.4	Moderate	High
Cattail	Headwaters/Middle Fork	4.0	2.7	0.6	5.8%	10.5	3.3	0.2	4.5	16.5	1.4	Moderate	High
Cattail	Headwaters/South Fork	8.0	3.4	1.0	6.3%	30.0	4.5	0.3	6.0	15.0	1.3	Confined	High
Devils Hole	Lower/Mainstem	10.0	1.9	1.0	1.9%	10.0	4.0	0.3	10.0	13.3	2.5	Unconfined	High
Devils Hole	Lower TRF Tributary	15.0	4.4	0.3	2.5%	5.0	2.5	0.3	5.5	8.3	2.2	Moderate	Moderate
Devils Hole	Middle TRF Tributary	35.0	2.4	0.3	3.3%	1.0	2.0	0.3	12.0	6.5	6.0	Channelized	Low
Devils Hole	Upper TRF Tributary	15.0	5.2	0.4	5.5%	2.5	2.2	0.3	15.0	8.8	6.8	Moderate	Moderate
Devils Hole	Lower Firehouse Tributary	20.0	3.8	0.1	2.2%	4.5	2.5	0.3	4.0	10.0	1.6	Moderate	Low
Devils Hole	Middle Firehouse Tributary	15.0	2.7	0.2	3.1%	0.5	1.5	0.5	3.0	3.0	2.0	Moderate	Low
Devils Hole	Upper Firehouse Tributary	12.0	7.8	0.7	4.7%	2.0	3.5	0.2	5.5	17.5	1.6	Moderate	High
Devils Hole	Lower SWFPAC Tributary	10.0	2.2	0.2	6.6%	8.0	3.0	0.5	5.0	6.0	1.7	Confined	Low
Devils Hole	Middle SWFPAC Tributary	10.0	1.8	0.3	2.1%	3.5	2.0	0.2	3.0	10.0	1.5	Unconfined	High
Devils Hole	Upper SWFPAC Tributary	15.0	8.0	0.5	4.9%	5.0	4.0	0.3	12.0	16.0	3.0	Moderate	Low
Devils Hole	Lower Sturgeon Road Tributary	10.0	4.0	0.6	2.0%	3.5	2.0	0.2	4.0	10.0	2.0	Moderate	Low
Devils Hole	Middle Sturgeon Road Tributary	15.0	5.0	0.5	3.0%	0.5	1.5	0.2	4.0	7.5	2.7	Moderate	Low
Devils Hole	Upper Sturgeon Road Tributary	25.0	6.6	0.4	5.4%	0.5	1.5	0.3	3.5	5.0	2.3	Moderate	Low
Clear Creek	Headwaters/North Fork	30.0	2.2	1.5	2.5%	2.0	1.5	0.2	3.5	7.5	2.3	Moderate	Low
Clear Creek	North Fork/Mainstem	20.0	2.2	2.7	3.3%	3.0	3.0	0.3	5.0	12.0	1.7	Moderate	Moderate
Clear Creek	Headwaters/Middle Fork	30.0	4.4	3.0	1.4%	0.5	2.0	0.3	12.0	6.7	6.0	Channelized	Low
Clear Creek	Middle Fork/Mainstem	15.0	2.5	4.0	2.0%	1.0	3.3	0.3	5.0	10.0	1.5	Unconfined	High
Clear Creek	Headwaters/South Fork	20.0	3.3	1.2	3.3%	6.5	2.0	0.2	3.0	10.0	1.5	Channelized	Low
Clear Creek	South Fork/Mainstem	15.0	3.0	2.5	2.0%	3.0	4.5	0.3	9.4	13.2	2.1	Moderate	Moderate
Clear Creek	Lower West Branch	15.0	3.3	6.5	0.5%	1.0	4.5	0.4	6.5	11.3	1.4	Moderate	Moderate
Clear Creek	Lower East Branch	20.0	2.5	7.8	0.5%	1.0	4.0	0.4	6.0	10.0	1.5	Moderate	Low
Clear Creek	Lower Mainstem/Silverdale	30.0	5.0	14.5	0.5%	1.0	5.0	0.4	7.0	12.5	1.4	Confined	Low

Habitat Data

Streambank Stability	Rosgen Stream Type	Soil Index	Dominant Soil Type	LWD Frequency (#/km)	LWD Frequency (#/BFW)	LWD Volume (m^3/km)	LWD Volume (m^3/LWD)	% POOLS LWD-Formed	% LWD Coniferous	% LWD >0.5m DIA	% LWD BFW	LWD Recruitment Potential
4	C3	4	Alderwood	414	2.1	1234	3.0	75%	80%	70%	80%	1
4	B4	4	Alderwood	270	1.1	954	3.5	88%	85%	50%	45%	1
4	B4	4	Alderwood	322	1.1	878	2.7	81%	90%	55%	85%	1
3	A4	4	Alderwood	345	1.6	1111	3.2	77%	90%	60%	85%	1
4	C4	4	Alderwood	240	1.0	1260	5.3	83%	90%	95%	40%	1
3	C4	4	Alderwood	178	0.4	915	5.1	80%	80%	90%	50%	1
2	E4	4	Alderwood	2	0.0	1	0.5	35%	10%	0%	25%	4
3	B4	4	Alderwood	133	0.3	278	2.1	77%	65%	40%	65%	2
2	C4	4	Alderwood	78	0.2	222	2.8	82%	75%	85%	60%	1
2	B4	4	Alderwood	33	0.0	58	1.8	55%	40%	10%	35%	4
3	B4	4	Alderwood	148	0.5	333	2.3	78%	50%	55%	75%	2
3	B4	4	Alderwood	225	0.7	787	3.5	69%	90%	40%	50%	2
4	B4	4	Alderwood	180	0.4	409	2.3	66%	50%	45%	55%	1
2	B4	4	Alderwood	220	0.9	370	1.7	85%	70%	35%	50%	2
2	C4	4	Alderwood	222	0.4	456	2.1	60%	45%	40%	40%	2
3	B4	4	Alderwood	112	0.2	333	3.0	75%	30%	25%	50%	2
2	B4	4	Alderwood	155	0.2	278	1.8	66%	25%	30%	30%	2
2	E5	4	Alderwood	3	0.0	1	0.3	30%	15%	5%	45%	4
3	C4	4	Alderwood	122	0.4	278	2.3	90%	45%	35%	60%	3
2	E5	4	Alderwood	5	0.0	2	0.4	25%	10%	5%	65%	4
3	C4	4	Alderwood	200	0.7	757	3.8	90%	80%	90%	75%	3
2	B4	4	Alderwood	6	0.0	9	1.5	60%	70%	50%	50%	4
4	B4	4	Alderwood	165	0.7	579	3.5	85%	73%	55%	70%	1
3	F5	5	Alderwood	78	0.4	101	1.3	80%	40%	30%	75%	4
2	F5	6	Alderwood	33	0.1	44	1.3	83%	15%	20%	40%	4
2	F5	7	Alderwood	40	0.2	72	1.8	80%	25%	25%	50%	4

Habitat Data

Pool Frequency (#/km)	Pool Spacing (#BFW's)	Pool Area (m^2/km)	Mean Pool Area (m^2)	Mean RPD (m)	Pool Cover (%)	% Pool Habitat	Pool Quality	Pool Diversity	LWD Quality	% Riffle Habitat	Riffle Quality	% Glide Habitat	Dominant Morphology
78	2.6	155	2.0	0.22	60%	48%	4	3	4	44%	4	8%	Pool-Riffle
70	3.6	120	1.7	0.13	55%	40%	3	3	3	55%	3	5%	Riffle-Pool
81	3.7	134	1.7	0.11	60%	44%	3	3	4	50%	3	6%	Riffle-Pool
77	2.9	122	1.6	0.15	50%	50%	3	3	3	45%	3	5%	Riffle-Pool
100	2.5	240	2.4	0.25	80%	45%	4	3	4	40%	4	5%	Pool-Riffle
82	4.9	190	2.3	0.20	75%	40%	3	3	4	55%	4	5%	Pool-Riffle
20	25.0	15	0.8	0.30	10%	10%	1	1	1	30%	2	60%	Glide
54	8.4	122	2.3	0.20	55%	40%	3	2	3	50%	3	10%	Pool-Riffle
69	5.8	155	2.2	0.20	75%	40%	3	3	3	40%	3	20%	Pool-Riffle
56	11.9	66	1.2	0.20	60%	35%	2	2	2	45%	2	20%	Glide
60	4.8	134	2.2	0.20	70%	35%	2	2	3	55%	3	10%	Pool-Riffle
78	4.3	95	1.2	0.30	75%	40%	3	3	4	55%	4	5%	Riffle-Pool
80	6.3	88	1.1	0.20	60%	30%	2	2	4	65%	4	5%	Riffle-Pool
48	5.2	100	2.1	0.25	75%	40%	3	2	4	55%	4	5%	Riffle-Pool
69	7.2	78	1.1	0.20	40%	30%	2	2	2	45%	2	25%	Riffle
78	8.5	101	1.3	0.20	55%	30%	2	2	2	45%	3	25%	Riffle
95	7.0	111	1.2	0.25	50%	35%	2	2	2	40%	2	25%	Riffle
28	23.8	77	2.8	0.25	15%	20%	1	1	2	40%	2	40%	Glide
66	5.1	333	5.0	0.20	50%	35%	2	2	3	45%	3	20%	Pool-Riffle
22	22.7	44	2.0	0.40	10%	10%	1	1	2	35%	2	55%	Glide
80	3.8	640	8.0	0.25	25%	45%	3	3	4	45%	3	10%	Pool-Riffle
44	11.4	225	5.1	0.15	40%	25%	2	2	3	55%	3	20%	Riffle
40	5.6	525	13.1	0.38	45%	18%	3	2	3	69%	4	13%	Riffle
33	6.7	444	13.5	0.33	35%	20%	2	2	2	30%	2	50%	Glide
26	9.6	569	21.9	0.40	25%	15%	1	1	1	25%	2	60%	Glide
30	6.7	800	26.7	0.47	10%	22%	2	1	2	35%	2	43%	Glide

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13. ABSTRACT *(Maximum 200 words)*

Surface and stormwater conditions on the Naval Submarine Base (NSB), Bangor, Washington, are evaluated, and recommendations are made to improve water quality and enhance the ecological integrity of aquatic resources located on the base. NSB, Bangor, is located within the upper Hood Canal watershed, a sensitive and ecologically important area of Puget Sound. The base is the only major industrial facility on Hood Canal and as such has a unique responsibility to protect this valuable natural resource. Based on a thorough assessment of physical, chemical, and biological conditions in streams, wetlands, and lakes within the base, an integrated surface and stormwater management (SSWM) plan is developed. This plan is built around a watershed-based, resource-driven approach for protecting aquatic ecosystems from the effects of human activities. The SSWM plan includes specific recommendations for improving stormwater best management practices with the goal of reducing the quantity of stormwater runoff and improving water quality. Application of innovative techniques for managaing stormwater runoff and for nonpoint-source pollution control was a high priority. The stream protection strategy is a long-range, on-going process that will require close cooperation with local county and tribal agencies. This plan could serve as a modelfor other Department of Defense facilities in the Pacific Northwest region and could be adapted to other areas of the country as well.

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