# CHARACTERIZATION OF SHORELINE ERODIBILITY AND RECREATIONAL BOAT-GENERATED WAVE EROSIVITY ON THE FOX RIVER CHAIN O' LAKES

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## Introduction

The purpose of this study is to characterize shoreline materials with respect to their inherent erodibility and consequent sensitivity to wave impacts. The study area is located within the Illinois portion of the Fox River watershed, and contains the Chain O' Lakes and portions of the Fox River. The Chain O' Lakes is a series of interconnected glacial lakes, and the Fox River is a principal tributary that conveys headwaters into the Chain O' Lakes and flows downstream from the Chain O' Lakes into the Illinois River. The study area encompasses approximately 123 miles of shorelines. The termini of the study area are at the Wisconsin/Illinois state line and Route 62 in Algonquin.

## Methodology

Shorelines along the study areas were mapped with respect to the types and proportions of materials, surficial parent materials, and surface soil types. Sampling transect locations were determined through use of this mapping information. Field sampling entailed 1) shoreline soil sample collection, classification, and testing; and 2) slope and plant cover characterization. Soil erodibility factors were then determined for each sampling site's soil type(s).

Erosivity characteristics of recreational boat-generated waves impacting Fox River Chain O' Lakes shorelines were determined by 1) using numerical relationships derived for computing maximum heights of recreational boat-generated waves, effective wind velocities and durations needed to generate similar wave heights, and various wave properties; 2) using boat count and Fox River Chain O' Lakes users' telephone survey response data to determine approximate mean numbers of waves generated by recreational boats: and 3) correlating the aforementioned data with corresponding shoreline material mapping and erodibility characterization sampling transect data.

## Conclusions

Approximate proportions of structurally unprotected shorelines along the erosion study area shown in Table 1.

*Table 1. Study area shorelines.*

| Study Area Component | Approximate Proportion (%) of Structurally Unprotected Shoreline | | |
|---|---|---|---|
| | WI/IL State Line to McHenry Lock and Dam | McHenry Lock and Dam to Algonquin | Total Erosion Study Area |
| Lakes | 52 | NA | 52 |
| Channels | 72 | NA | 72 |
| Rivers | 31 | 56 | 49 |
| **Total** | **50** | **56** | **53** |

Approximately 12% of the erosion study area shorelines between the Wisconsin/Illinois state line and Route 62 in Algonquin are city, county, state, or privately owned parkland, of which 91% are structurally unprotected shorelines.

Surficial parent material deposits along the erosion study area shorelines consists of a) peat, muck, or marl; and b) glacial tills having various combinations of sand, silt, and gravel. Soil types present along sampling sites ranged from coarse gravels to silty clays and peats. Coarse-grained soils were primarily present along lake, exposed soil, and grass/lawn shorelines, while fine-grained soils were primarily present along channel and tree/shrub shorelines. A majority of the Fox River Chain O' Lakes shoreline soils contain high to very high levels of organic matter.

The sampling transects had level to very steep slopes. Slope steepnesses per gradient zone generally decreased as the number of backshore gradient zones increased. Classification of sampling transect slope steepnesses indicates that backshore slope zones are subjected to high erosive forces.

The principal zone-of-influence for wave impacts within swash zones is basically consistent for structurally unprotected Fox River Chain O' Lakes shorelines with regard to lengths of swash zones measured during sampling. Swash zones ranged from two to 17 feet in length. Heights of nearly vertical slopes encountered during sampling ranged from five to 34 inches. Most of these nearly vertical slopes occurred at water-shoreline interfaces and also had undercut banks.

Slope shapes of the sampling transects were predominantly convex, while there were similar proportions of slopes having uniform and concave shapes. Convex slopes generally experience faster surface runoff velocities than concave and uniform slopes.

Structurally unprotected channel and river shorelines have more undercut banks and are more susceptible to bank failures than those along lake shorelines. Tree/shrub shorelines are highly susceptible to bank undercut and potentially experience more severe bank failures than those composed of grass/lawn and exposed soil cover. Angularity of undercut banks was steepest in clay soils and most gradual in silts.

The effects of plants upon undercut bank stability can be very significant. Root masses generally help retain soil peds, thereby increasing bank stability. However, the presence of plants along banks can result in increased loss of bank material during their failure process.

Erodibility of soils increases as their soil erodibility factor (K) values increase. Proportions of sample-site soils having K values greater than the maximum of those for clays and gravels indicate that structurally unprotected channel and river shorelines and shorelines composed of exposed soil and tree/shrub cover are the most susceptible to erosive agents, with tree/shrub shorelines being the most susceptible. It can be assumed that shorelines composed of cattails are equally or more susceptible to erosive agents than tree/shrub shorelines.

Defining L as length of boat, $w_t$ as wake type zone-of-influence, $H_m$ as maximum wave height, x as distance between boat and wave gage (shoreline), U as effective wind velocity, $F_e$ as effective wind fetch, d as depth of water at boat, and $K_w$ as rate of soil loss per wave impact, empirical and boat-count site relationship results indicate that:

a) Per L and $w_t$, $H_m$ values decrease as x increases.

b) Per L and $w_t$, U values needed to generate respective $H_m$ values decrease as x increases.

c) $H_m$ values increase as L values increase.

d) $H_m$ are highest within transition zones, intermediate within open zones and least within no wake zones.

e) Per U, $H_m$ increase as $F_e$ increases.

f) The impacts recreational boats have on wave generation are very substantial when compared to the impacts of wind on wave generation.

g) Wave heights of waves generated by an average Fox River Chain O' Lakes wind velocity are negligible when compared to those of recreational boat-generated waves.

h) Per L and $w_t$, $H_m$ values decrease as x/d increases.

i) Per L and $w_t$, U values decrease as x/d increases.

j) $H_m$ values increase as L values increase.

k) $H_m$ values are highest within transition zones, intermediate within open zones, and least within no wake zones.

l) $K_w$ decreases as x/d increases.

m) $K_w$ increases as L values increase.

n) Per L and $w_t$, $K_w$ tends to decrease as x/d increases.

o) Shorelines along transition zones experience faster $K_w$ than shorelines along open and no wake zones, with $K_w$ being least along no wake zone shorelines.

Both the number of waves generated per hour and per day on weekends were three times greater than those generated on workdays. Structurally unprotected shorelines within the vicinity of the boat-count sites are substantially susceptible to wave impacts, especially structurally unprotected shorelines within transition zones.

The product of soil erodibility factor and wave power values used in trend analysis shows that mean rates of soil loss per wave impact were five times faster along shorelines within transition zones than those along open zones.

Non-Corps of Engineers' resource management actions that would produce *positive impacts* upon erosion (e.g., reduce rates of accelerated erosion) are those that: a) reduce boat velocities near shorelines; b) move zones of boat passage away from shorelines, especially transition zone locations; c) decrease the number of boats using the waterways, that is, reduce the number of wave impacts; d) decrease the maximum range of boat lengths allowed on the waterways; e) optimize boating operations that minimize travel distances needed to transcend to and from open and no wake zone velocities and that maximize streamlining of hulls; f) provide streambank protection (which can also produce *negative impacts*); and/or g) reduce fetch.

A Corps of Engineers' permitting activity that would impart *positive impacts* upon erosion is to "Approve on Case Basis if other Limits are in Place." Positive impacts would ensue if mitigation requirements, for instance, streambank protection, were included with permit approval.

# FEMA: LOMR(ABQ) = $Q_{100} + Q_S$
# (IN ALBUQUERQUE, FEMA INCLUDES SEDIMENT IN THE FLOOD EQUATION)

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## Albuquerque's Geologic Setting

Flood control agencies in the arid Southwest United States are becoming increasingly aware of the impacts of the sedimentation process when determining flood-prone areas and designing drainage facilities. Located in central New Mexico, at an elevation between 4900 and 6300 feet, the City of Albuquerque experiences much of the sedimentation problems common to the Southwest. Because of some unique terrain features, there are aspects of alluvial processes that present special challenges to Albuquerque's engineers and floodplain administrators.

Immediately west of the city, the Manzano and Sandia mountains steeply rise to an elevation over 10,000 feet. Through the center of the city, sediment deposition in the Rio Grande and the construction of levees have caused the river to be several feet higher than the surrounding developed areas. Between the mountains and the Rio Grande, an alluvial fan zone lies at the mountain front, followed by a 3 to 4% slope pediment zone. The upper portion of the pediment zone is incised and armored with large boulders. Most of the pediment is a depositional zone with shallow braided arroyos and frequent avulsion areas. To the west of Albuquerque is a relatively flat topped mesa that is underlain by deep sand and gravel from old alluvial deposits. Base lowering of the Rio Grande over geologic time has resulted in development of high density drainage and badlands areas at the mesa slope.

## Development and Sedimentation History

Development in Albuquerque has mostly occurred along the Rio Grande floodplains and on the sloped pediment below the mountains. The western mesa tops and slopes have only recently begun to experience rapid development. As areas developed, natural arroyos were replaced by storm sewers and concrete-lined trapezoidal channels. Traditional drainage analysis has largely ignored the potential for sediment problems at these facilities. The National Flood Insurance Program (NFIP) mapping is largely based in earlier studies that did not consider sediment impacts on dams and constructed channels, and did not consider the potential erosion of natural arroyo banks. Where all of a watershed was fully developed with lined channels, this was not a problem. However, many watersheds in the area have substantial undeveloped areas and natural conveyances. At these locations, sediment can impact constructed facilities and existing development.

In 1981, a report titled *Design Guidelines and Criteria for Earth Channels and Hydraulic Structures on Sandy Soils* (Simons, Li and Associates, Inc., 1981) was prepared for the Urban Drainage and Flood Control District in Denver, Colorado. This report quickly became a standard guidebook for Albuquerque, and in 1983 was incorporated by reference into an update of the *Development Process Manual* (City of Albuquerque, 1982). The *Manual* contained the following guidance concerning sedimentation:

> A channel's stability can be defined in terms of its ability to function properly during a flood event without serious aggradation and/or degradation. . . While channel stability problems are largely associated with earth and flexibly lined channels, concrete lined, supercritical channels are not immune.

From 1982 to 1990, these provisions were *not* generally addressed by local engineers and agencies when preparing or reviewing plans.

In 1987, two new dams (Raymac and Don Felipe) were completed in southwest Albuquerque. In June 1988, a storm in the watersheds above the dams produced over 10 times the sediment volume that had been predicted during the design of these facilities. A major storm at the Embudo Canyon watershed on July 9, 1988, produced substantial amounts of water and sediment damage, and resulted in one death. Video recordings taken during the storm clearly indicated high concentrations of sediment. Photos of plugged arroyo channels and large rocks on bridge railings provided further evidence of sediment and debris problems. Following this storm, the Federal Emergency Management Agency (FEMA) "postponed" further review of revisions to the NFIP maps for the Albuquerque area. Reviews were re-initiated in March 1990 with the following requirement:

> Because of the alluvial nature of watersheds and streams contributing to flood hazards in the City of Albuquerque, each request for a revision to the Albuquerque FIRM and FBFM will require supporting information on how the sedimentation

> and debris processes impact the base (100-year) flood. . . Since the City of Albuquerque experiences flooding of an alluvial nature, all requests submitted after October 1, 1989 must either demonstrate that the site in question is not subject to alluvial flood hazards or comply with Section 65.13.

FEMA suggested that the U.S. Army Corps of Engineers (Corps) engineering manual, *Sedimentation Investigations of Rivers and Reservoirs* (U.S. Army Corps of Engineers, 1989) would provide comprehensive guidance for evaluating sedimentation and debris conditions. They noted that the Corps document was "FEMA's primary reference in reviewing proposed changes to FIRMs and FBFMs involving alluvial conditions." After reviewing this document and following consultation with local Corps technical staff, it became apparent that the Corps manual did not provide detailed guidance necessary for analysis of 100-year flood conditions at the steep ephemeral arroyos common to the Albuquerque area. In order to obtain this detailed guidance, the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) retained the firm of Resource Consultants and Engineers, Inc. to prepare a *Sediment and Erosion Design Guide* (Resource Consultants and Engineers, Inc., 1994). A public review draft of the Design Guide was available in March 1992, and in August 1992, a "pilot course" was conducted to review the document and receive input from area engineers and agencies. In March 1993, FEMA staff provided review comments that contained the following statements:

> We have reviewed the draft version of the report and find it to include valuable procedures customized to the Albuquerque and Bernalillo County area which address the requirements for managing alluvial channels. In addition, the report outlines the parameters appropriate for planning and designing drainage facilities in the floodplains in this area, including projects which may require issuance of a Letter of Map Amendment (LOMA) or Letter of Map Revision (LOMR) by FEMA. . . We believe that this design guide will be useful in the design of these facilities, and that used in conjunction with the appropriate NFIP regulations, can be used to satisfy the requirements outlined in our letter dated March 8, 1990.

Following input from agencies and extensive additions to the procedures identified in the draft, the final version of the Design Guide was released by AMAFCA in March 1994.

## Lateral Erosion—the Prudent Line and Erosion Envelope

An important element of the Design Guide was the establishment of a setback distance from natural arroyos to avoid or minimize the potential for damage due to flooding and erosion; the setback location has been named the "prudent line." The concept considers both long-term erosion, which can occur over many years due to a series of frequent runoff events, and short-term erosion, which results from a single 100-year storm. AMAFCA currently uses a 30-year period to define long-term erosion. The prudent lines are defined by the 100-year floodplain limits, or by the additive effects of short-term and long-term erosion, whichever is greater. Included with the Design Guide is a computer program, CURVCALC, that can be used to estimate lateral erosion migration for channels based on bend geometry, bank height, and sediment transport. While the prudent line procedure is essential for many projects, it is analytically complex and time intensive. An alternate procedure was established to estimate maximum erosion distance based on geomorphic relationships between the meander wavelength, channel width, and minimum radius of curvature of a channel bend; this procedure defines the "erosion envelope."

## Sediment Transport

Total sediment concentrations of 500,000 ppm by weight have been documented in arroyos. Such concentrations can increase the volume of the water sediment mixture by 40% or more. Few, if any, available sediment transport relationships are applicable for these conditions. The work of H.S. Woo (1985) resulted in a complex differential equation to account for the significant changes in fluid characteristics with increases in sediment concentrations. Mussetter (in press) linked Woo's relationship with the Meyer-Peter & Muller (MPM) bed-load equation to obtain a method for computing bed material in streams carrying high concentrations of suspended sediment. Results obtained from this method were compared with the results from other available relations and, to the extent possible, with measured yield data. The new method should provide more realistic results over the range of flow and sediment transport conditions encountered in the Albuquerque area. The MPM-Woo method was used to estimate bed material transport capacity for a broad range of hydraulic and bed material conditions typical of the Albuquerque area. The results of these computations were then used by Mussetter to develop the following power function relation using multiple regression:

$$q_s = a\, V^b\, Y^c\, (1 - C_f)^d \qquad (1)$$

where $q_s$ is the bed material transport capacity in cubic feet per second per foot of width, V is the velocity in feet per second, Y is the flow depth in feet, $C_f$ is the fine sediment concentration in ppm by weight, and the coefficient (a) and exponents (b, c, and d) can be determined from Figure 1.

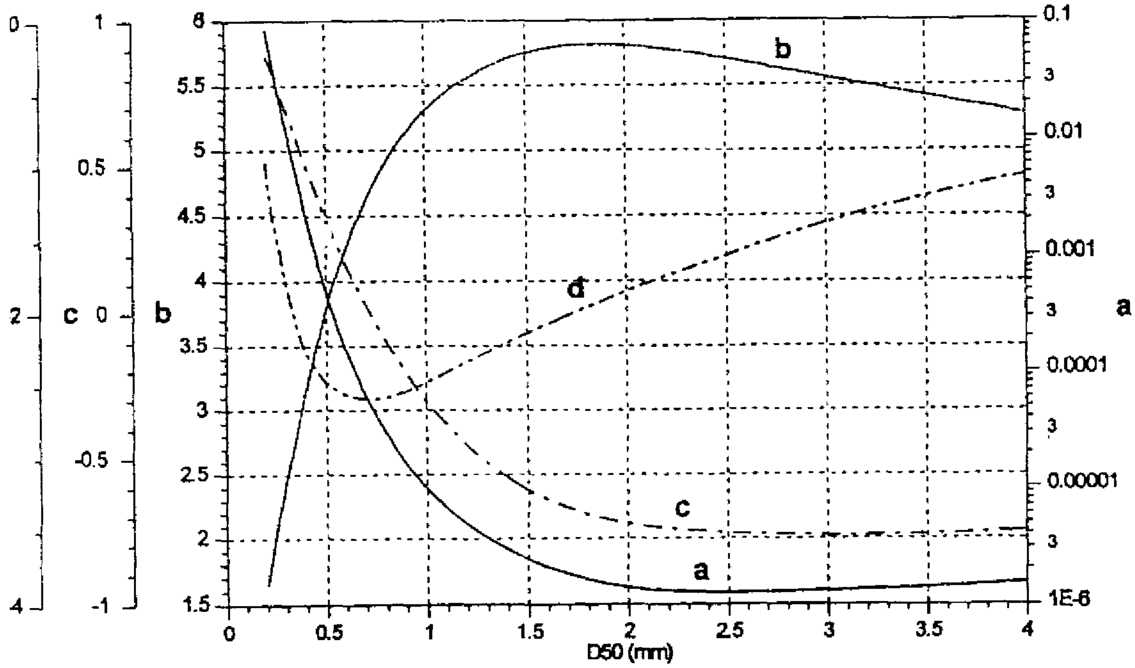


*Figure 1. Coefficient and exponents for Equation 1.*

## Flood Wall Scour

The computation of scour at a flood wall adjacent to a natural arroyo has become an important design consideration for many developments and is a logical consequence of lateral erosion analysis. When flow impinges on a wall at a sharp angle, the procedures commonly used for bridge abutments can provide guidance for flood wall design. When flow is parallel to a wall, the bridge abutment procedures are not directly applicable, and scour may be more related to relative shear stress. For most flood wall conditions at arroyos, flow is not likely to be parallel under all conditions, and will commonly impinge on the wall at an angle. The potential scour at an arroyo changes as the arroyo evolves in planform. The angle of impingement can be estimated based on the ideal meander geometry and the available unconstrained valley width. With the flow angle established, Mussetter developed the following relationship for determining scour depth:

$$(Y_s / Y_1) = [(0.73 + 0.14 \pi F_r^2) \cos \theta] + [4 F_r^{0.33} \sin \theta] \qquad (2)$$

where $Y_s$ is depth of scour, $Y_1$ is flow depth, $F_r$ is Froude number, and $\theta$ is the angle between the flow direction and the flood wall.

## Other Sediment Issues

The Design Guide provides information on aggradation, annual sediment yield, antidune scour, armor layers, bulking factors, continuity analysis, contraction scour, culvert outlets, detention and debris ponds, equilibrium slope, geomorphology, Manning's roughness, pier scour, trap efficiency, and counter-measures (i.e. riprap, soil cement, check dams, spur dikes, guide banks, jetties) that are essential elements of a comprehensive sediment evaluation. In addition, an interim procedure for determination of avulsion probabilities (Heggen, 1994) is allowing a systematic evaluation of this condition.

## Conclusions

It is anticipated that the above concepts and relations will provide a practical tool to evaluate sedimentation in the Albuquerque area. For similar areas in the arid Southwest, the Design Guide procedures may provide the alluvial watershed information required by FEMA for the NFIP.

## References

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# SEDIMENT MANAGEMENT AND REGULATION IN WASHINGTON STATE

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Alluvial rivers draining from the Cascade and Olympic Mountain ranges in western Washington State transport large sediment loads to downstream locations. Deposition in downstream channel reaches may reduce channel capacity, leading to increased frequencies and magnitudes of flooding. Removal of gravel from riverbeds is one of a number of alternatives that can be considered by affected jurisdictions to reduce flood hazards to downstream residents. While the action may be supported by local residents, regulatory, environmental, and economic issues need to be addressed before a program of removals can become a viable alternative.

KCM, Inc. is currently preparing a Comprehensive Flood Hazard Management Plan (CFHMP) for the Nooksack River in Whatcom County, Washington (see Figure 1). The Nooksack River, with a mean annual flow at Ferndale of 3,867 cfs, drains the western slopes of the Cascade Mountains. A portion of Mount Baker, a glaciated inactive volcano with a peak elevation of 10,750 feet, contributes flow at the river headwaters.

## Nooksack River Case Study

The Nooksack River is subject to severe flooding. The most recent major flood event, in November of 1990, caused damages estimated by the U.S. Army Corps of Engineers to be $21 million. The 57,000-cfs flow gauged at Ferndale during this event is estimated to have a recurrence interval of 50 years. During large events like the 1990 flood, the river overflows its banks at Everson and floodwaters are conveyed north into Canada. The resulting flooding causes considerable damage and disruption to important facilities in British Columbia. This transboundary flooding is the major focus of the Nooksack River International Task Force, made up of U.S. and Canadian officials.

The severity of the 1990 flood and other recent floods prompted the County Commissioners to form a Flood Control Zone District and fund the Comprehensive Flood Hazard Management Plan. As one element of the plan, KCM has completed a preliminary analysis of issues relating to gravel management in the Nooksack River. The analysis focused on historical practices and current status of gravel removals, a preliminary economic analysis, and a regulatory review including compilation of performance standards required by

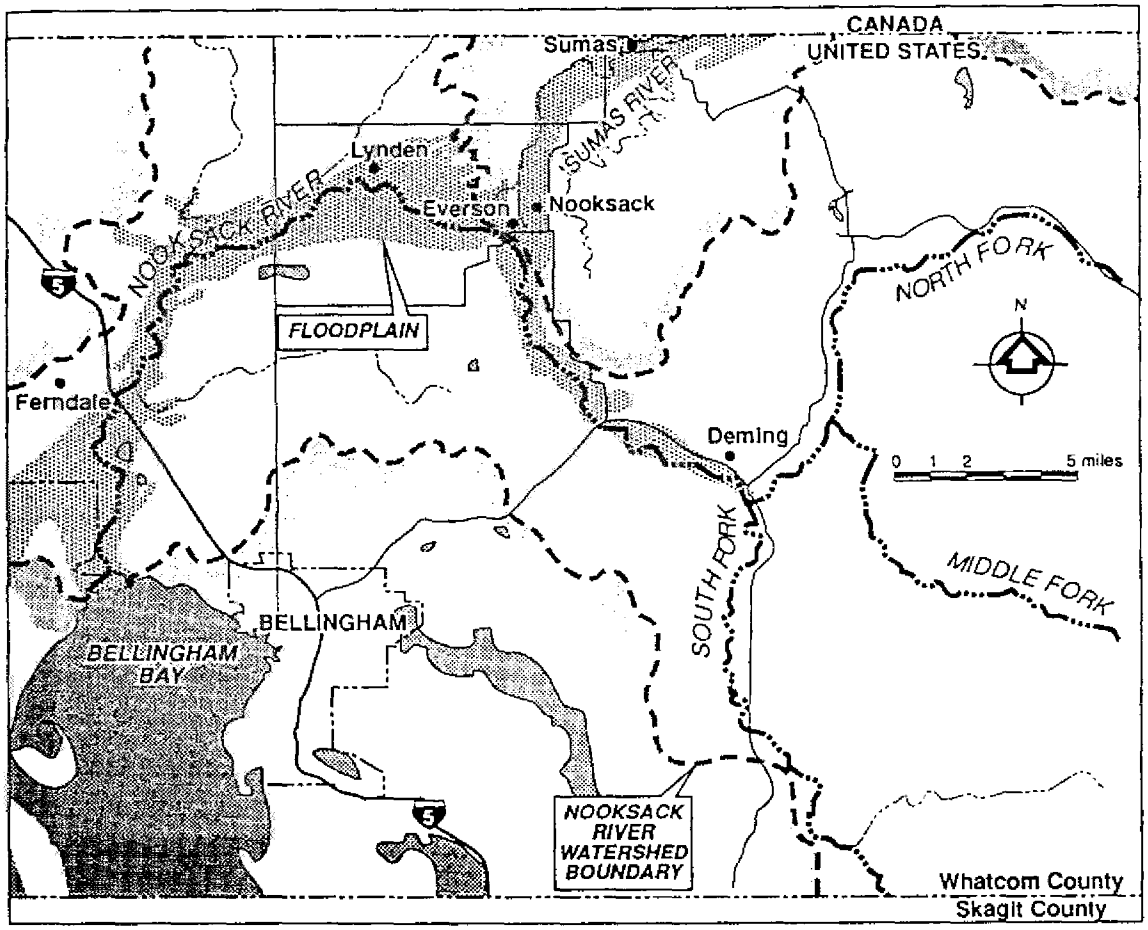


*Figure 1. Lower Nooksack River Comprehensive Flood Hazard Management Plan study area, Whatcom County, Washington.*

relevant regulations. This work, coupled with other CFHMP tasks, is intended to answer the following questions:

- Is sediment accumulation a major cause of flood problems?
- Can gravel removal be an effective flood hazard management strategy?
- Does gravel removal cause adverse environmental impacts?
- What are the practical problems of gravel removal? (For example, how much gravel can the market absorb?)
- Is sediment accumulation causing more frequent and larger overflows at Everson, and if so, should the channel be dredged?

## Historical Practices, Current Status, and Economics

As the three forks flow out of the western foothills of the Cascade Mountains, they carry substantial quantities of sediments along steep river reaches. In the vicinity of the confluences of the three forks, the river slope decreases dramatically. Decreased river slopes reduce transport capacity, resulting in deposition of coarser materials in braided reaches in the vicinity of and downstream from Deming. Sediment grain sizes decrease with distance along the river and the river generally flows within a single channel downstream of Everson.

To determine the amount of gravel present in any reach of a river, the following components must be known:

1. The amount deposited from the watershed or from upstream reaches of the river;

2. The amount deposited from erosion of the channel banks within the reach being studied;

3. The amount conveyed downstream with the river flow; and

4. The amount removed from the reach by excavation.

Quantification of these components will determine the feasibility of reducing flood hazards by removing gravel. To estimate one of them—the amount removed by excavation—records of past removal were examined. The amount of gravel removed in the past can approximate how much can reasonably be removed in the future. This estimate can then be compared to calculations of how much gravel must be removed to reduce flooding. These calculations have yet to be performed.

Gravel has been removed from the Nooksack River for over 30 years for a variety of purposes. Private operators, who have carried out the majority of gravel removal, are generally responsible for obtaining required permits, excavating the material, processing it, finding purchasers, and transporting the material to the purchaser. Operators are required to obtain a lease agreement and report regularly to the Washington State Department of Natural Resources on the volume of gravel they remove. Data from these reports were used to establish a data base of information on past gravel removal volumes. Annual removal volumes were extracted from the data base.

The total reported volume of gravel removed annually from 1960 to 1993 ranged from none to 252,000 cubic yards. The level increased substantially from 1990 to the present. Average annual gravel removal was 55,700 cubic yards from 1963 through 1987 and 191,800 cubic yards from 1990 to 1993, an increase of over 300%. River gravel removed by operators is used for a variety of purposes, including cement concrete, asphalt concrete, drain material, and gravel backfill. Current removal practices to obtain raw materials for these products include the following steps:

1. Logs, roots, and other large woody materials are removed from the surface of the bar.

2. Gravel is excavated by either pushing material into a windrow (a long linear pile) using a bulldozer and carrying it off the bar with a front-end loader, or moving material to a stockpile out of the river using a self-loading scraper/earth mover.

3. Gravel is transported from the bar to the shore by way of temporary routes built along the shoreward portion of the bar. Where allowed by permit, temporary bridges are used to cross low water channels. Bar-to-shore routes are washed away with seasonal high water and therefore frequent re-establishment is required.

4. Gravel is transported from the shore to a county road or nearby processing area. Access charges based on the amount of material transported are often assessed for private property crossings.

5. Raw river gravel may be processed to produce secondary products. Processing can involve washing, crushing, and screening the gravel. It can also be mixed with other materials to make such products as cement concrete and asphalt concrete. Stockpiles of unprocessed and processed material are sometimes produced.

6. Raw or processed materials are transported to the end user along public roadways.

The cost to excavate gravel from a Nooksack River bar and transport it to a processing site within three miles is estimated to be from \$2.00 to \$2.50 per cubic yard. The cost for transport beyond approximately three miles is additional and varies with distance.

Prices paid by buyers of river gravel depend on how the gravel is processed. Raw pit run gravel is typically sold in Whatcom County for \$5.00 to \$6.00 per cubic yard delivered. If the material is screened and washed, the price increases to approximately \$9.00 to \$10.00 per cubic yard.

## Regulations and Performance Standards

A number of local, state, and federal regulations apply to gravel removal in rivers, with objectives ranging from collection of fees for extraction of state-owned resources to protection of fisheries. Pertinent regulations are:

- County Shoreline Management Program (SMP),
- Washington State Aquatic Land Management Regulations,
- Washington State Hydraulic Code Rules,
- Washington State Environmental Policy Act (SEPA),
- Section 401 of the Clean Water Act,
- Section 402 of the Clean Water Act, and
- Section 404 of the Clean Water Act.

Performance standards for gravel mining activities are required on a site-specific basis by state and local agencies with jurisdiction over gravel removal. These requirements are described in permit conditions developed from published regulations and are based on permit application materials and visits to the proposed project site. Permits issued under the County Shoreline Management Program and the State Hydraulic Code both contain site-specific performance standards. A summary of the typical performance standards listed in these permits and their rationale is presented in Table 1.

## Conclusions

The preliminary analysis summarized here is a first step in the potential development of a sediment management program to reduce flood hazards along the Nooksack River. This work will be coupled with future analyses to:

1. Locate areas of net deposition of sediment,
2. Predict the level of flood reduction for various gravel removal plans,
3. Determine the economics of making gravel removal viable, and
4. Define environmental issues and determine ways to address them.

**Table 1. Performance standard rationales for gravel removal projects.**

| Performance Standard | Rationale |
|---|---|
| Uniform removal of gravel from bars | Non-uniform removal could promote channel changes during flood events |
| Total amount of sediment removed from the bars should not exceed the amount of sediment entering the system | Maintains sediment balance equilibrium |
| Limited working hours | Minimizes negative impacts on nearby property owners |
| Limitations on screening, washing, crushing, and stockpiling gravel on bars | Activities may contribute sediment and other pollutants to river, degrading fish habitat and water quality |
| Seasonal limitations on gravel removal activities | July to August is the preferred time for gravel removal activities because the majority of salmon outmigration has occurred by this time, return of adult fish upriver has not started, gravel bars are accessible due to low flows, and risk of floods are low |
| Slope requirements (typically 0.5 to 2 percent), potholes to be filled in, berm prohibited between the water and the bar | Reduces likelihood of fish stranding |
| No equipment allowed to enter area of flowing water | Avoids disturbance of fish habitat, reduces potential for pollution from oils, greases, and other contaminants on heavy machinery |
| Site specific prohibitions on gravel removal including requirement of riprap installation | Prevents bank erosion in areas of higher erosion potential |
| Prohibition against cutting standing timber close to the bank and timber greater than 6 inches in diameter | Protects fish habitat—standing trees provide shade and reduce water temperature; roots maintain stability of soils near banks |
| Blind channels and pits within them | Blind channels are channels excavated to the side of the main channel and connected it at one end; the channels and excavated pits associated with them enhance fish habitat during gravel removal and allow for additional volumes of gravel to be removed during scalping operations |
| Placement of stumps and logs in blind channels | Enhances fish habitat |
| Noise level restrictions | Minimizes negative impacts to nearby property owners |
| Refueling to be done landward of the OHWM and off the gravel bars | Reduces potential for pollution from oils, greases, and other contaminants on heavy machinery |
| Hazardous spill response plan required | Provides direction in case of accidents, and minimizes potential for water pollution. |
| Vehicular access restrictions including construction of paved access aprons, wetting of access roads, prohibition against tracking mud and debris on County roads, sight distance requirements for access points from work sites to County roads, obtaining easements for access | Minimizes potential for air and water pollution, protects health and safety, and meets legal access requirements |

Sediment management can become an important part of a flood hazard management program on the Nooksack River if quantifiable flood hazard reductions are found to be achievable, gravel mining operations are conducted according to all relevant regulations, and the economics of excavation and use of river gravel are favorable.