ANALYSIS OF FLOODING IN THE SKAGIT RIVER DELTA AREA

Submitted to
Federal Emergency Management Agency
Office of Natural and Technological Hazards

By

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1. INTRODUCTION

An analysis was made of 100-year flooding conditions in the Skagit River delta area as requested by the Federal Emergency Management Agency in a meeting with Dames & Moore on August 25, 1982. The analysis was undertaken to establish flood elevations for the delta area using the Skagit River floodflows determined by the U.S. Army Corps of Engineers (COE) in 1979 (Reference 1). It is planned that the results of this analysis will be used for the Flood Insurance Studies for Skagit County and the incorporated communities of Burlington, La Conner, and Mt. Vernon, Washington.

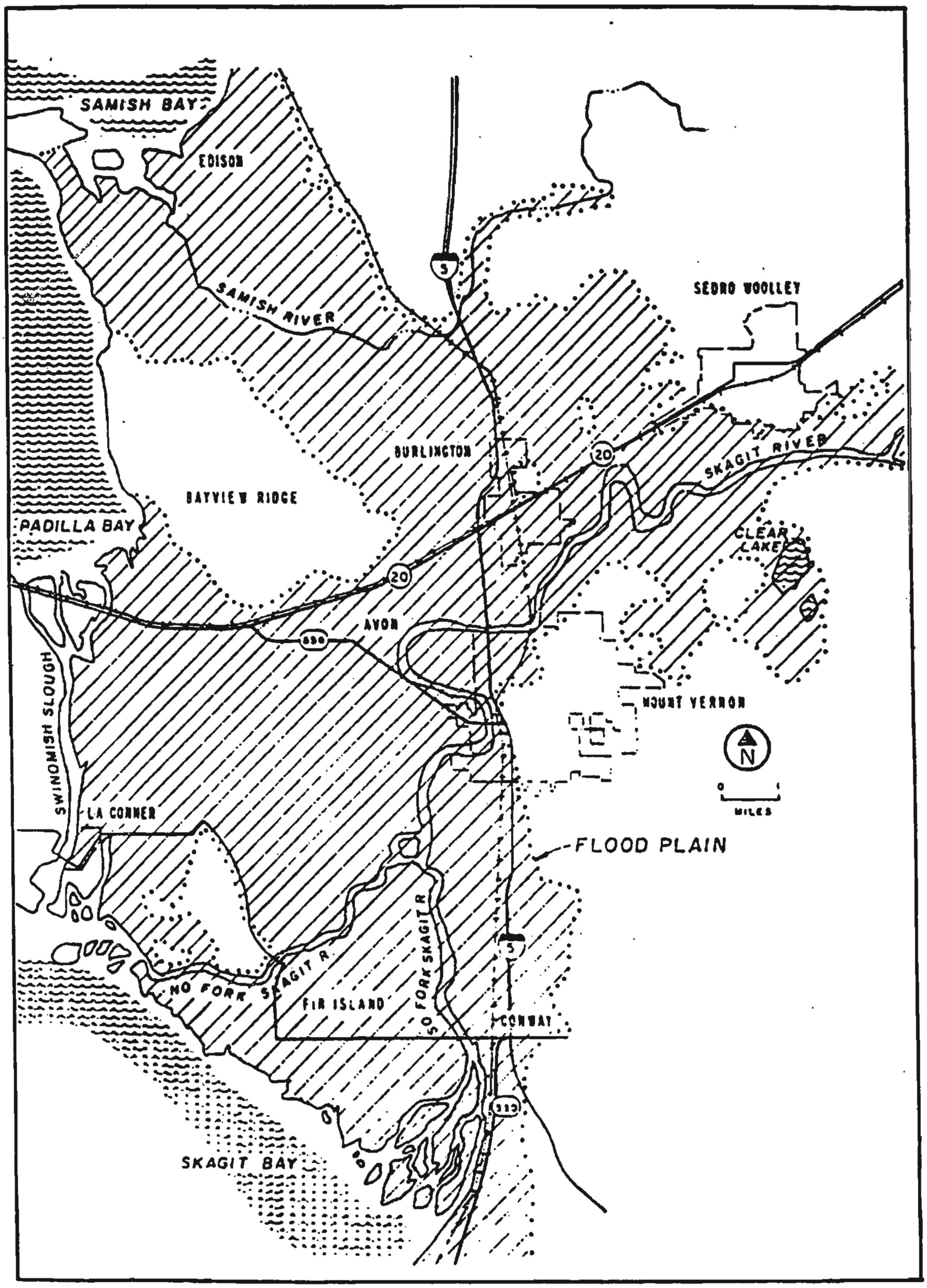
The Skagit River represents the major flooding source of the delta area. Flooding occurs from multiple levee failures and bank and levee overtopping during a 100-year flood. Downstream of Sedro Woolley, the Skagit River flows through a large delta area that fronts Padilla and Skagit Bays. Within this area, the flood plain forms a large alluvial fan with an east-to-west width of approximately 11 miles and a north-south width of 19 miles. Communities subject to flooding within this reach are Burlington, Mount Vernon, and La Conner (Figure 1). Sixteen diking districts maintain approximately 56 miles of levees and 39 miles of sea dikes in the Skagit River delta, but none of the levees or dikes are adequate to protect against a 100-year tidal or riverine flood (Figure 2).

2. HYDROLOGY

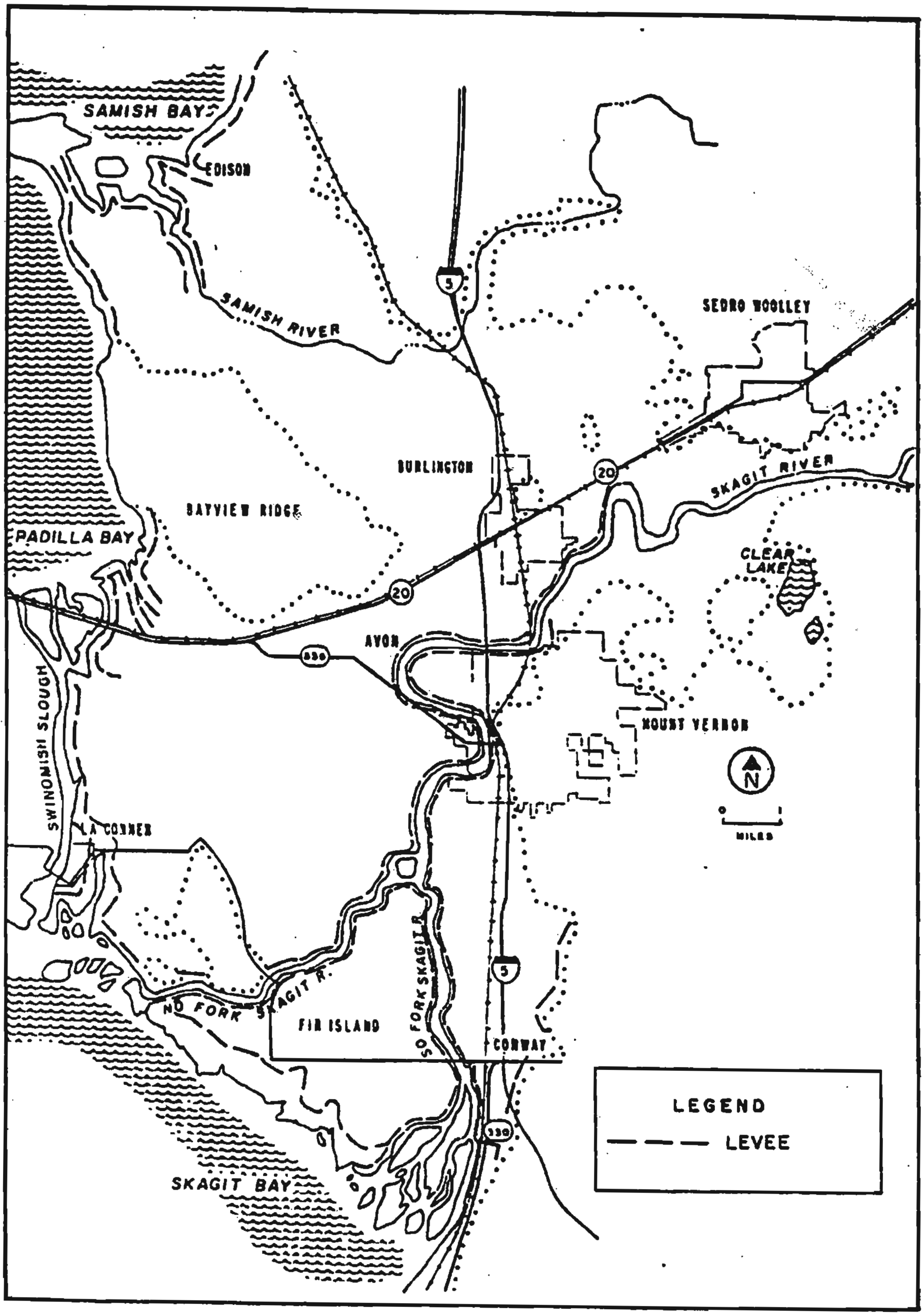
The 100-year flood discharge downstream from Sedro Woolley was estimated to be 240,000 cubic feet per second (cfs) by the COE (Reference 1). Historical flooding events have shown that discharges within the channel and existing levees will reach a maximum of 130,000 cfs before levee overtopping and failure will occur. The flood of 1975 reportedly caused levee-full conditions and thus was assumed to represent maximum channel and existing levees flooding conditions during a 100-year event. For this analysis, 110,000 cfs were assumed to flow in the channel and the remaining 130,000 cfs were assumed to flow in the overbanks during the 100-year event. The overbank flooding flows past Burlington and divides to flow through the Samish River flood plain into Padilla Bay and through the Skagit River flood plain into Swinomish Slough and Skagit Bay.

Because of the complex nature of the divided overbank floodflows, it was necessary to perform several HEC-2 analyses (Reference 2) for a range of discharges along each path. The results were used to develop stage-discharge rating curves for each path. From these rating curves, discharges were selected for each path; the discharges produced a common elevation at the point of bifurcation of the two paths. It then was determined that 86,000 cfs will flow into Padilla Bay, and 44,000 cfs will flow into Skagit Bay (Figure 3).

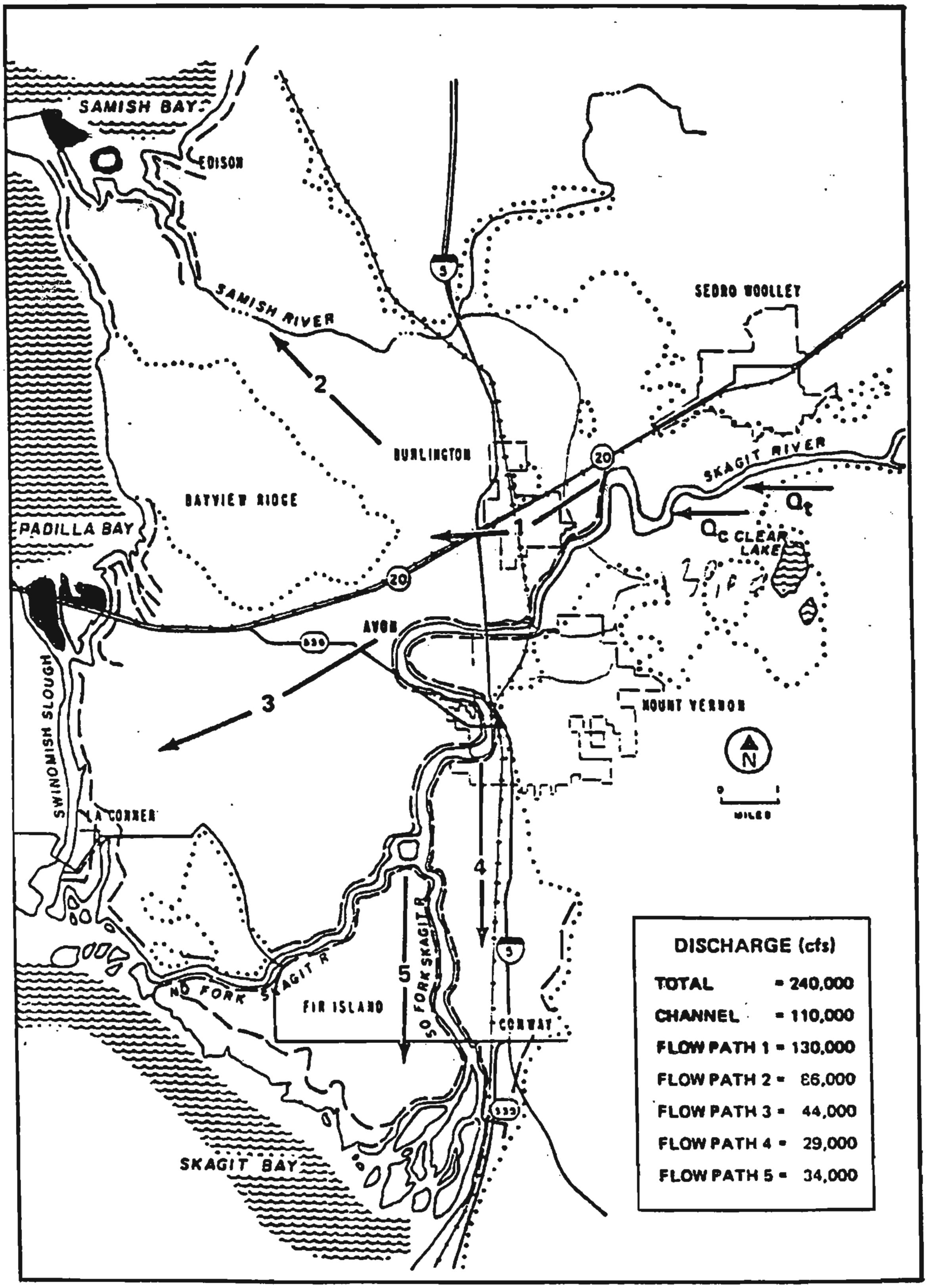
The 100-year flooding east of the Skagit River in the vicinity of Mount Vernon and between the North and South Forks of the Skagit River is caused by levee failure. Peak discharges of 29,000 cfs and 34,000 cfs, respectively, were



EXISTING CONDITIONS 100-YEAR FLOODING
FIGURE 1



EXISTING LEVEE SYSTEM
FIGURE 2



DISCHARGE (cfs)

TOTAL	= 240,000
CHANNEL	= 110,000
FLOW PATH 1	= 130,000
FLOW PATH 2	= 86,000
FLOW PATH 3	= 44,000
FLOW PATH 4	= 29,000
FLOW PATH 5	= 34,000

DISCHARGE DISTRIBUTION IN DELTA AREA

FIGURE 3

determined using the weir flow equation for a single levee breach located at the upstream point of each flow path (Figure 3). These discharges were used to compute the 100-year water-surface elevations along each of the respective flow paths.

3. HYDRAULICS

Water-surface elevations for all flow paths were computed using the HEC-2 computer program (Reference 2). Use of the computer model was replaced or supplemented with hand calculations in certain areas and situations where such methods were considered to be more suitable. It was assumed that the coastal levees would contain the riverine flooding until they were overtopped. Therefore, the average levee crest elevation, 8 feet, was used as the starting water-surface elevation for the overbank flow paths. The common upstream elevation of the two flow paths was used as the starting water-surface elevation for the overland reach from just west of Interstate Highway 5 to Sedro Woolley. The elevated portions of Interstate Highway 5, west of Burlington, will obstruct this flow to some extent, but the highway ultimately will be overtopped.

Flooding of the area inside the meander loop, west of Avon, is caused by ponding due to overtopping of the Skagit River channel. The ponding elevation of this area is controlled by the minimum ground elevation of the point of exit from the channel between Interstate Highway 5 and the levee system.

Water-surface elevations for the Skagit River channel were taken from the flood profiles of the 1975 flood (Reference 1).

Flood profiles for the overbank flow paths were drawn showing computed 100-year flood water-surface elevations (Exhibit 1). The overbank flow path distances shown on the profiles were measured along the base lines indicated on the maps.

Depths of flooding used for areas subject to shallow flooding were determined by applying the computed average depth of flooding in the adjacent flow paths.

Cross section data for the delta area were obtained from aerial mapping (Reference 3), U.S. Geological Survey topographic maps (Reference 4), other topographic maps (References 5 and 6), and as-built drawings of Interstate Highway 5 (Reference 7). Terrain features, such as roads, railroads, and levees, that would have a hydraulic effect were considered by selecting the cross section locations to include and reflect the controlling effects of such features.

The Manning's "n" values used in the computation of flood profiles for the overbank flows were estimated based on review of aerial photographs (Reference 3) and a county land use map (Reference 8). Values for roughness coefficients ranged from 0.045 to 0.060.

The computed 100-year flood elevations are in agreement with the Sedro Woolley Flood Insurance Study (Reference 9).

4. FLOOD BOUNDARIES

The 100-year flood boundaries were delineated using the flood elevations determined at each cross section; between cross sections, the boundaries were interpolated using topographic maps at scales of 1:24,000, with a contour interval of 20 feet (Reference 4); 1:2,400, with a contour interval of 2 feet (Reference 5); and 1:2,400 with a contour interval of 5 feet (Reference 6). Aerial mapping at a scale of 1:24,000, with a contour interval of 100 feet (Reference 3), and construction as-built drawings (Reference 7) were also used in the interpolation.

The 100-year flood boundaries are shown on the work maps (Exhibit 2). Small areas within the flood boundaries may lie above the flood elevations and, therefore, not be subject to flooding; owing to limitations of the map scale, such areas are not shown.

5. FLOOD INSURANCE ZONES

The COE has estimated that the 10-year discharge of the Skagit River would be contained in the channel; therefore, the Flood Hazard Factors for the overland flows were determined by the average difference between the ground elevations and the 100-year flood elevations. The Flood Hazard Factors were used to determine the insurance zone designation listed in Table 1.

Flood insurance zones, and base flood elevations for each overbank flow path are shown on the work maps (Exhibit 2).

6. DENSITY CRITERIA

Conventional floodways are not appropriate for the complex flow conditions in the Skagit River delta. A more suitable flood plain management technique is to limit the density of development. Development density is defined to be that portion of a lot that is raised above the 100-year flood elevation to accomodate new construction or landscaping. Increasing the development density on one lot produces a negligible increase in water-surface elevation; however, the cumulative increase in water-surface elevation caused by all new development in the flood plain can be substantial.

The density criterion for flood plain management is the development density (measured in percent) that would result in a 1-foot increase in water-surface elevation if applied to every lot throughout the flood plain. Because the development density that causes water-surface elevations to increase 1 foot above present levels can be determined by hydraulic analysis, the density criterion provides an objective method of balancing benefits from flood plain development against flood losses.

The density criterion depends on lot size, average hydraulic depth, and average energy slope of the 100-year flood. In the hydraulic analysis described in Section 3, five separate flow paths were analyzed. The average hydraulic depth and energy slope was computed for each path. Graphs developed by the COE were used to determine the density criterion to be used for each flow path and lot size (Reference 10). Results are shown in Table 2.

Table 2. Density Criterion for Flood Plain Management (%)

Lot Size (Acres)	Path 1	Path 2	Path 3	Path 4	Path 5
0.25	5	7	8	7	5
0.50	7	8	10	9	6
1.00	8	9	12	10	7
3.00	9	10	13	12	9
5.00	10	11	14	13	10

The density criterion varies from 5 percent to 14 percent depending on the flow path and the lot size. For example, suppose a land owner wishes to construct a building on a 1-acre lot in Flow Path 4. The table shows that the owner can raise a maximum of 10 percent (4356 square feet) of his property above the 100-year flood plain.

To make flood plain management regulations easier to enforce, a 10-percent density criterion for all flow paths and lot sizes is recommended.

7. REFERENCES

1. U.S. Department of the Army, Corps of Engineers, Skagit River, Washington: General Design Memorandum, Levee Improvements, Seattle, Washington, July 1979

2. U.S. Department of the Army, Corps of Engineers, Hydrologic Engineering Center, HEC-2 Water-Surface Profiles, Users Manual, Davis, California, 1976

3. State of Washington, Department of Natural Resources, Orthophoto Maps, Scale 1:24,000, Contour Interval 100 feet: T.36N. R.2E. (1974); T.36N. R.3E. (1974); and T.36N. R.4E (1974)

4. U.S. Department of the Interior, Geological Survey, 7.5-Minute Series Topographic Maps, Scale 1:24,000, Contour Interval 20 feet: Alger, Washington (1952), Photorevised (1968), Inspected (1973); Bow, Washington (1954), Photorevised (1968), Inspected (1973); Conway, Washington (1956), Photorevised (1981); LaConner, Washington (1956), Photorevised (1973); Mount Vernon, Washington (1956), Photorevised (1973); Utgalady, Washington (1956), Photorevised (1968), Inspected (1973)

5. Leonard and Boudinot, Inc., Topographic Maps, South Interceptor Sewers, Preliminary Design, Scale 1:2,400, Contour Interval 2 feet: City of Burlington, Washington (May 1979), Revised (February 1980)

6. Walker and Associates, Inc., Aerial Topographic Maps, Scale 1:2,400, Contour Interval 5 feet: City of Mount Vernon, Washington (1975)

7. Washington State Highway Commission, Department of Highways, As-Built Drawings, Interstate Highway 5, Skagit County, Olympia, Washington, 1973

8. Skagit County Planning Department, *Official Zoning Map, Skagit County*, Scale 1:158,400, Mount Vernon, Washington, March 11, 1980, Revised December 17, 1980

9. Federal Emergency Management Agency, *Flood Insurance Study, City of Sedro Woolley, Washington*, January 1982

10. U.S. Department of the Army, Corps of Engineers, Hydrologic Engineering Center, *Hydraulic Methods for Evaluating Density Floodways*, Davis, California, August 1981