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CHAPTER 6-4

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6.4 River and Tidal Hydraulics

Hydraulics, simply stated, describes the work done by water. A major component of river hydraulics is sediment transport -- the movement of material by water. The mechanisms by which sediment is moved are different in different areas of the landscape. Uplands are generally areas where sediment is picked up. Lowland valley floodplains are areas where deposition and sorting take place. Estuaries are subject to tidal fluctuations, creating a unique transportation mechanism. This section covers sediment discharge, flood stages, overbank flooding, sea-level change, tide gauging, tidal datums, stillwater elevations and coastal flooding, tidal prism relationships, and head of tide.

6.4.1 River Flood Stages and Overbank Flooding

■ Objectives

The objective of this assessment was to compare river stage forecast data with recorded peak steamflow data to evaluate the relative severity, magnitude, frequency and duration of historic overbank flood events in the Tillamook bay basin.

■ Methods

River stage descriptions for the Wilson river were obtained from the National Weather Service River Forecast Center in Portland (Figure 6-4-1). Gauged flood flows were correlated to these river stages using the stage discharge relationship provided on the most recent USGS rating table (stage-discharge relationship) for the gauge (Rating Table No. 15, November 11, 1995). For example, the 14-foot river stage corresponding to moderate flooding was compared to the rating table, and this stage was associated with a river discharge of 15,790 cfs. A similar method was used to develop relationships for the other river stages shown in Figure 6-4-1.

An estimate of the duration of flooding -- days above flood stage -- on a water-year basis (October through September) was made by determining the number of mean daily flows at the Wilson River stream gauge that exceeded the NWS-designated flood stage discharge of 13,200 cfs (Figure 6-4-1). This evaluation assumes that flows exceeding the NWS flood stage discharge result in overbank flows in the lowland valleys. Hourly flows at the stream gauge were then evaluated to determine the total days of overbank flows within each water year (Figure 6-4-3). The same assessment was made for hourly flows from 1994-1998 (Figure 6-4-6).

■ Discussion

The flood stages described in Figure 6-4-1 are shown together with annual peak discharges for the period of record of the Wilson River gauge in Figure 6-4-2 to provide an assessment of the frequency and magnitude with which flood events exceeded the various flood stages.

Figure 6-4-3 indicates that brief periods of overbank flooding (up to one day) appear to have occurred on a more frequent basis throughout the early part of this century and up to the mid-1970s. The clusters of fairly regular annual flood pulses from 1942 to 1950 and 1961 to 1967 occured during a general period of wet, cool weather along the Oregon coast, and soon after the major burns in the Tillamook Basin. Both these conditions would tend to increase the potential for runoff and flooding. Since the 1970s, annual overbank flooding exceeding a day in duration appears to be more frequent, with durations up to three days. This may be an indication of more variable climatic conditions combined with upstream land use practices that are causing runoff to become more “flashy” and less regular in occurrence.

Figure 6-4-4 shows the distribution of hourly streamflows for the Wilson River stream gauge, and the frequency and duration of flows exceeding flood stage within the water years 1995 into 1998. The "pulsing" nature of streamflow is readily apparent in this figure, as represented by the dark spikes of hourly flow through the winter months. Overbank flows do not occur on a continual basis, but rather expand and retreat across the floodplain during flooding and drawdown. Floodplain lands within this extent of flood inundation experience high turnover rates of organic matter and nutrients (Bayley, 1995) and are important habitats for fish and wildlife. Figure 6-4-4 also shows that most of the annual pulsing in water level occurs below flood stage. This points to the importance of the riparian corridor along rivers channels, and the river banks themselves, as highly productive portions of the river system where the most dynamic interaction between land and water occurs.

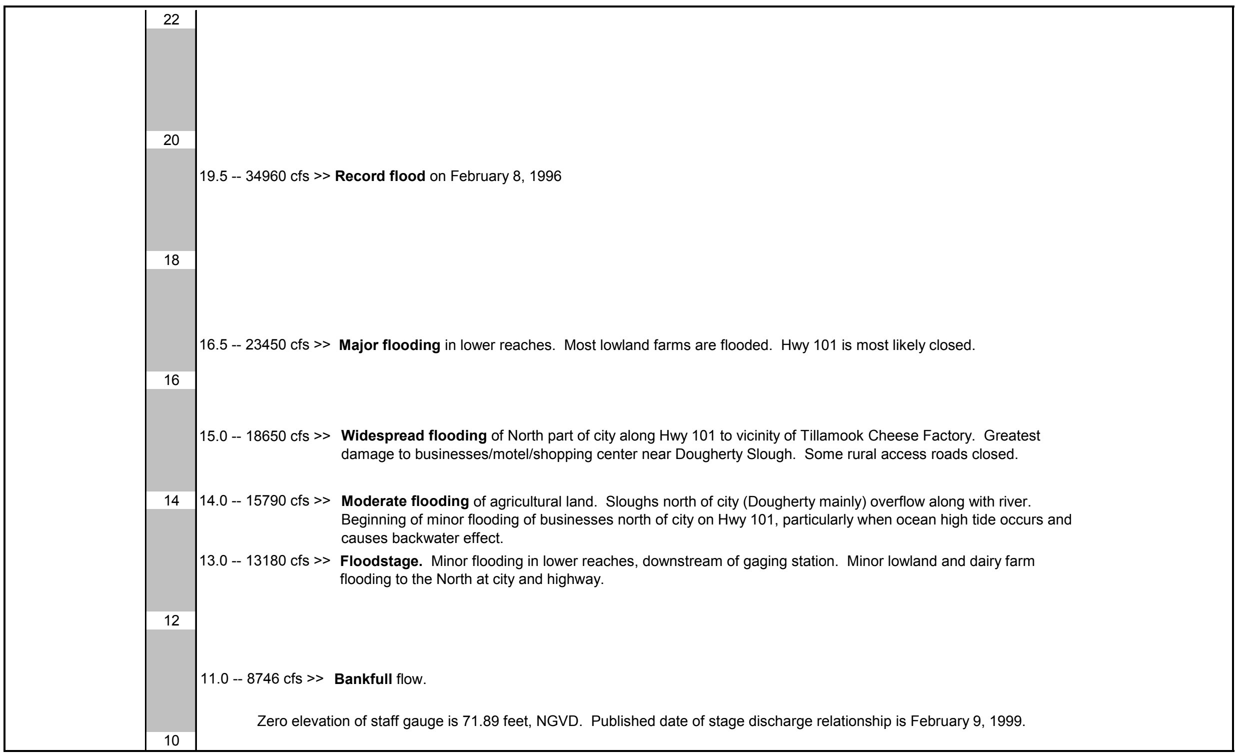

Figure 6-4-1. Wilson River Flood Stages Source: NOAA, 1999

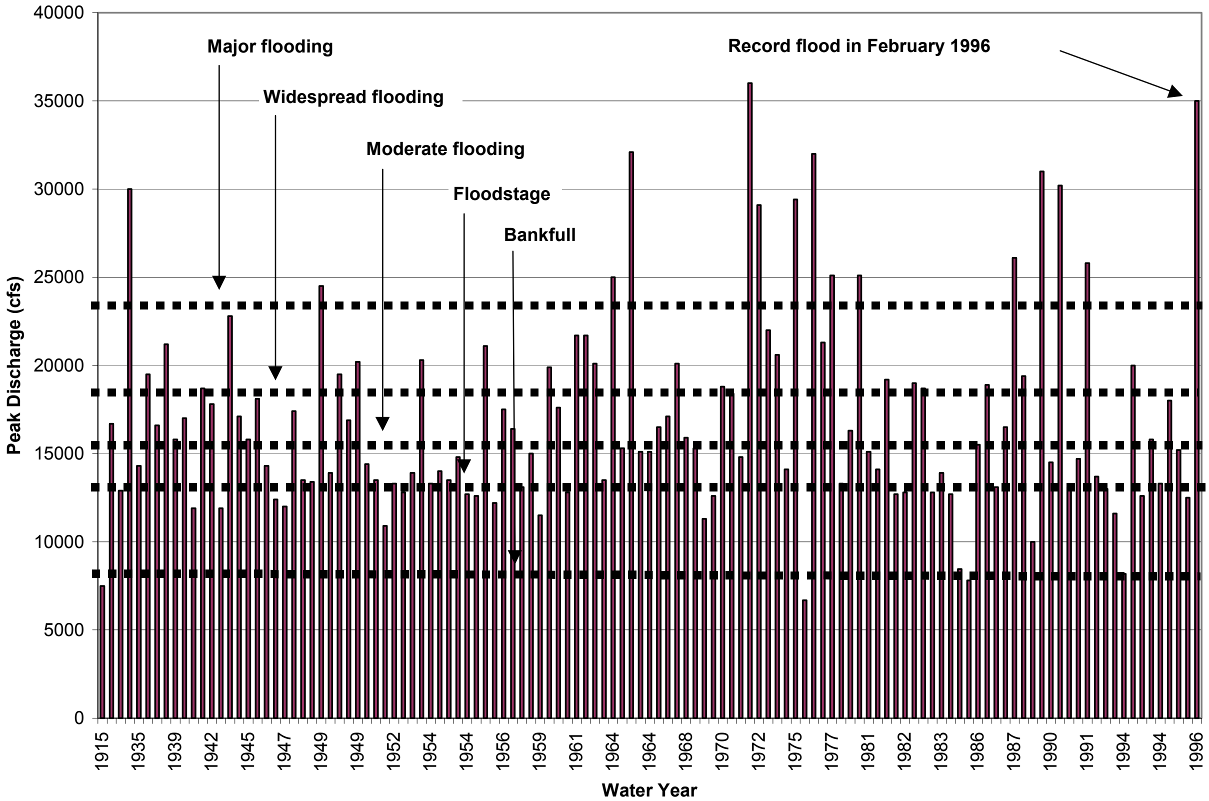

Figure 6-4-2. Wilson River Annual Peak Discharges in Relation to Flood Stages

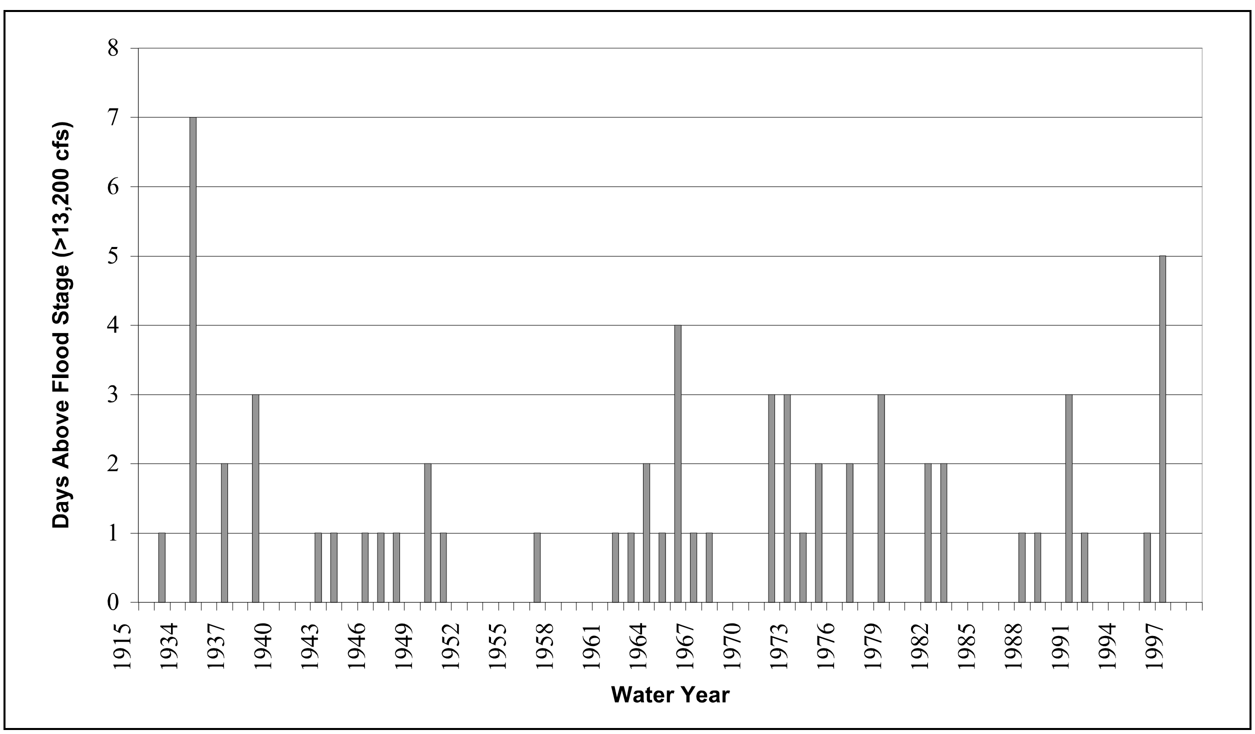

Figure 6-4-3. Days above Flood Stage for Historic Wilson River Floods

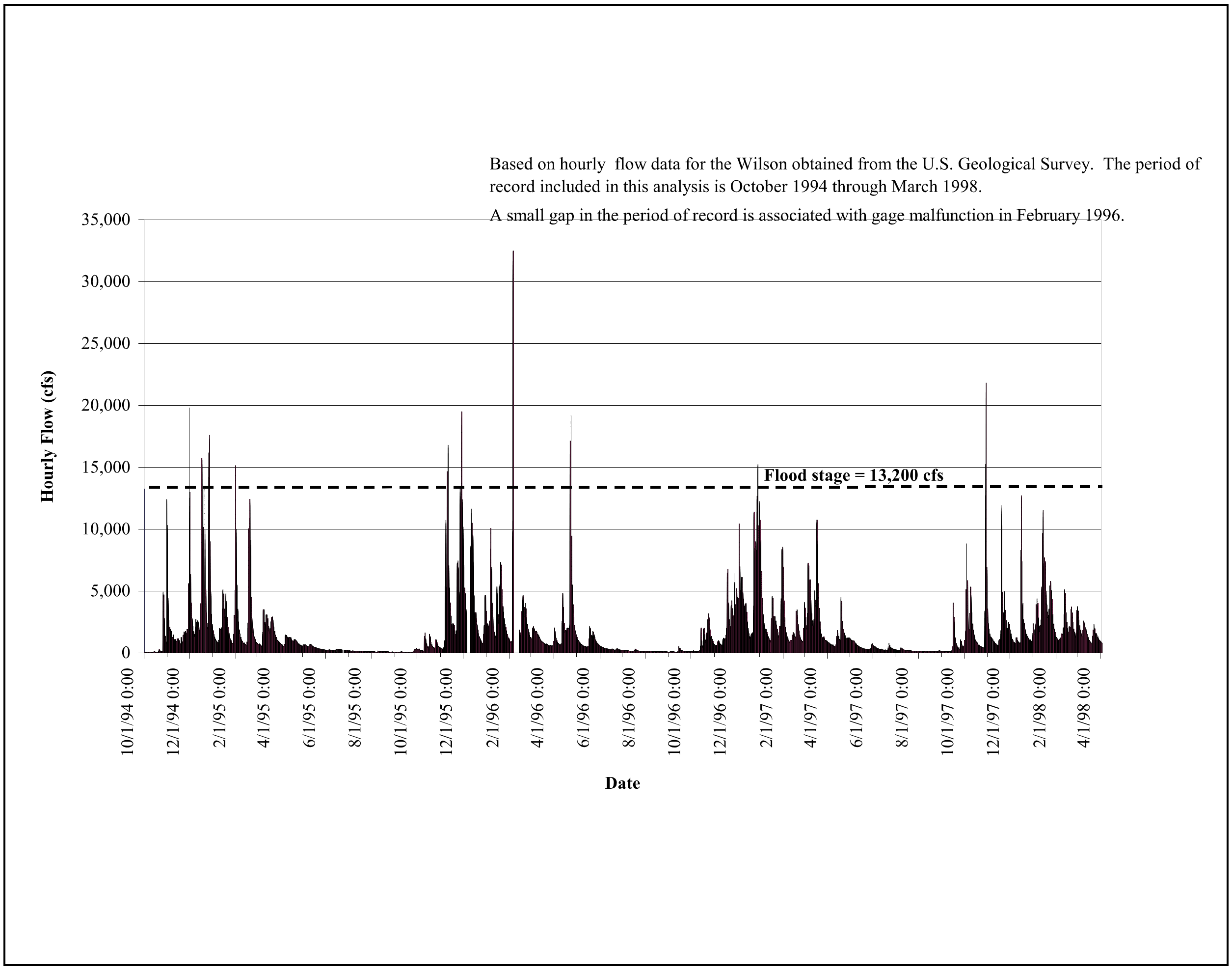

Figure 6-4-4. Hourly Flows about Flood Stage for Wilson River

6.4.2 Lowland Valley Flood Characteristics

▪ Objectives

Flooding is a dynamic physical process that can be extremely complex in lowland valley floodplains where flood flows combine and interact with the tides. The best method to describe lowland valley flood characteristics is through the use of computer models that can evaluate complex changes in water level and, with some models, the two-dimensional flow patterns of the flood waters. The Tillamook Bay lowlands were modeled in the 1970s as part of a FEMA flood insurance study using a one-dimensional steady state model (HEC-2). However, since the modeling was done about 25 years ago, it was not possible to retrieve from archives. The objective of this assessment was therefore to determine general flood characteristics in the lowland valley using available information and simplified methods.

Since many floodplains in Oregon have been evaluated by FEMA, a simplified method was devised to utilize FEMA data to identify flood characteristics. This method involved using estimated FEMA flood elevations and discharges, and delineating land drainage patterns. These methods should not replace, but rather complement, additional information that may be available from the application of computer models that can better describe the dynamic characteristics of flooding.

▪ Methods

Flood elevations from the FEMA flood profiles were compiled at key locations along each lowland mainstem river reach, typically at bridge crossings that were readily defined on the profiles. In the absence of FEMA data, high water marks from flood events can also be used to help define the maximum floodwater surface elevation. FEMA flood profiles show water surface elevations for the 500-, 100-, 50-, and 10-year flood events. From a flood management and aquatic ecology standpoint, the 10-year event is of more interest because of its more frequent occurrence. Water surface elevation contours for the 10-year event were sketched by interpolating between elevation locations (Figure 6-4-5).

Stream power values were estimated for the 10-year flood event in the lowland river reaches using FEMA flood insurance study data. FEMA flood profiles were used to determine elevations at key locations along the rivers, and published 10-year flood discharges were associated with these elevations. Flood elevations, and distances between the elevation locations, were used to estimate slopes across the 10-year flood water surface. The slopes were then used to roughly estimate stream power for the 10-year flood event. Stream power is a measure of a river's ability to do work, i.e., to move sediment and erode streambanks. Stream power was estimated using the expression $P = \gamma QS$, where γ is the unit weight of water (generally 62.4 pounds per cubic foot), Q is the discharge, and S is the water surface slope. The average of all values was determined, and stream power values were rated as low or high, based on whether they fell below or above the average value. Figure 6-4-6 provides a general indication of the lowland river reaches where stream power is relatively high for the 10-year flood event.

After a flood peaks and begins to recede, land drainage patterns begin to exert control over flood flow characteristics. Drainage patterns were generally identified by sketching flow arrows on a topographic map within the FEMA 100-year floodplain boundary. In this case, the topographic work map used to develop the FEMA floodplain was available and used; however, any large-scale map may be used in this kind of effort. Flow paths can also be observed from historic maps and aerial photographs. Figure 6-4-7 shows generalized land drainage patterns, and provides an indication of flow around floodplain encroachments and cross-flow between the lowland river channels.

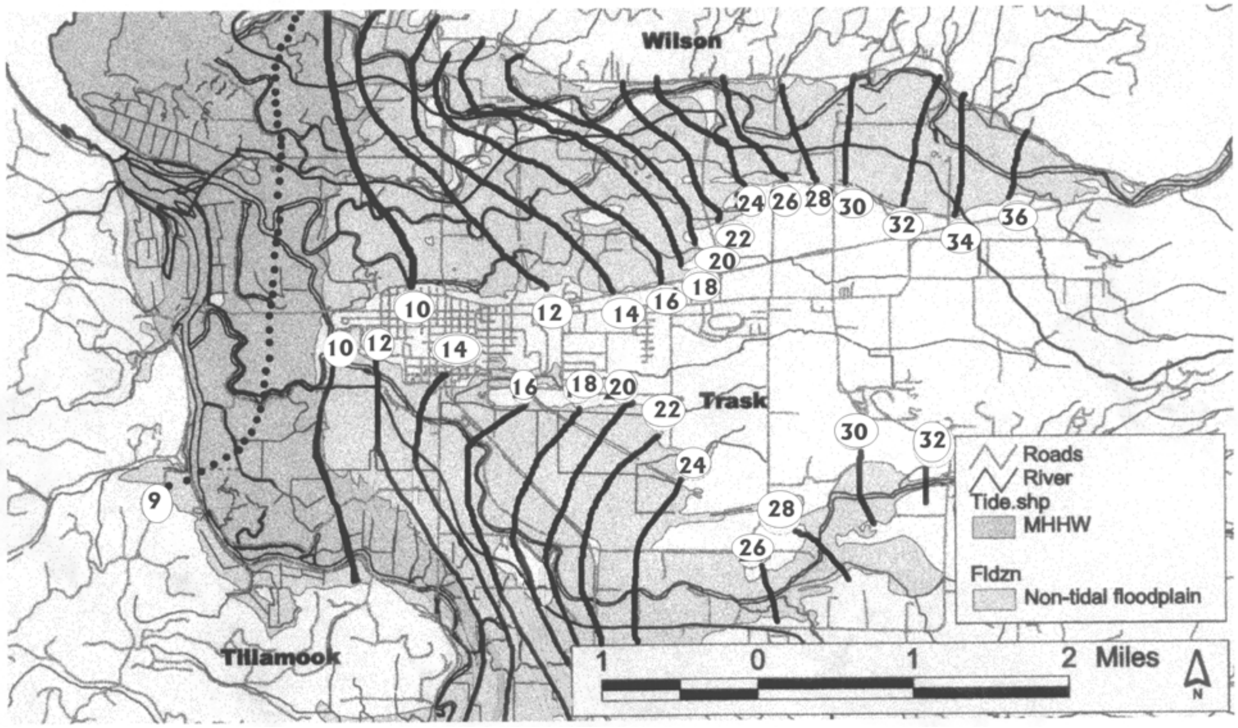

Figure 6-4-5. Generalized 10-Year Flood Water Surface Contours

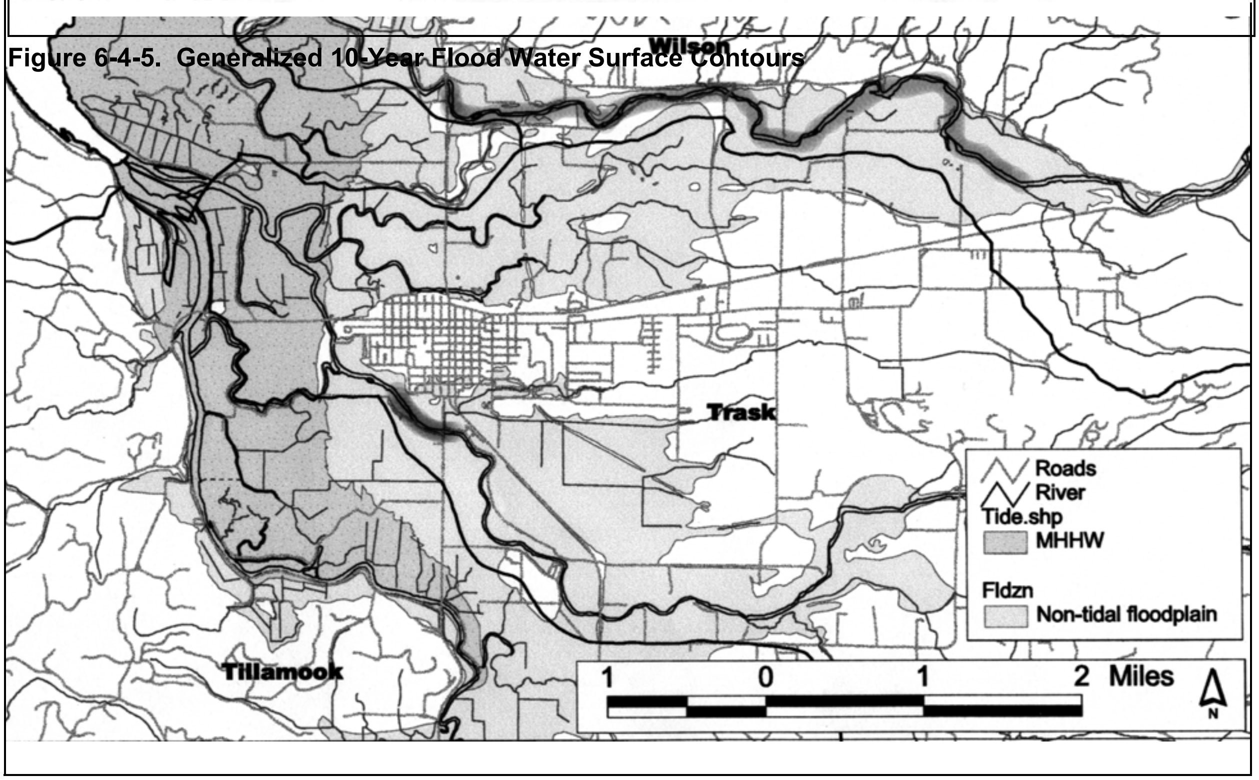

Figure 6-4-6. Relative Lowland Floodplain Stream Power Estimates

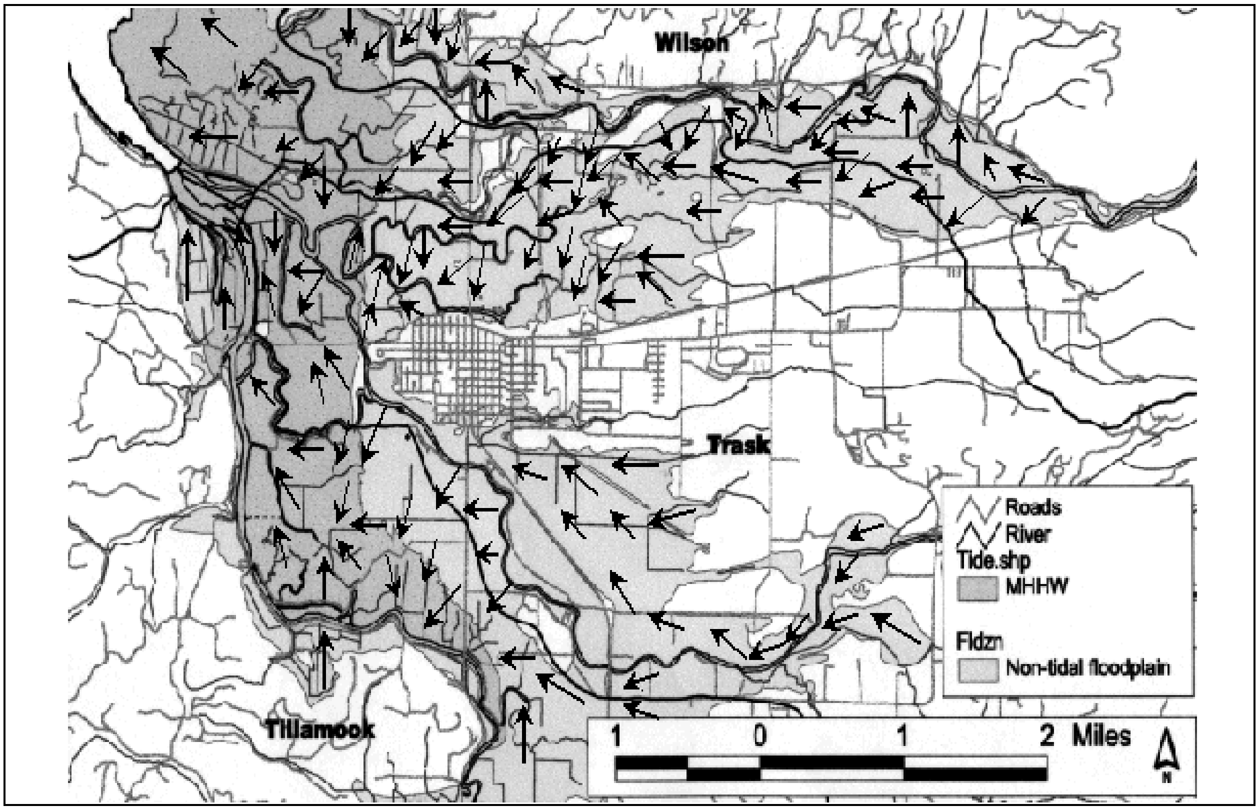

Figure 6-4-7. Generalized Land Drainage Patterns

In lieu of the use of a computer model to simulate the complex characteristics of flooding, simplified methods were used to describe lowland valley flood characteristics. The 10-year flood water surface elevation contours provide a glimpse of a hypothetical flood condition, where steeper slopes indicate higher energy flows, and flow directions can be estimated perpendicular to the contours. Based on this simplified assessment of the 10-year flood event, the contours indicate that overbank flood flow paths may be significantly different from river channel alignments. The bulk of the floodwater from the Wilson River flows in a southwest direction towards Dougherty and Hoquarten Sloughs. Trask River flows trend due west into the Tillamook River (Figure 6-4-5). Flood management efforts should address high energy flow areas, where flood gradients are steeper, by minimizing floodplain encroachments that may lead to or worsen land and riverbank erosion. Strategies should be developed that accommodate the direction of overbank flood flows between river and slough channel systems.

Estimated stream power values were lowest in the Tillamook River system and highest in the Wilson River system. Figure 6-4-6 shows the distribution of high and low power values for the lowland valley. Estimates indicate that a majority of the Wilson River reach upstream of Highway 101, and portions of the Kilchis and Trask River reaches in the vicinity of Highway 101 have high power values. Encroachments along these reaches, such as bridges and levees, should be evaluated carefully, and flood management strategies should be considered to reduce floodwater gradients and increase conveyance.

Land drainage patterns provide an indication of the effects of natural and human encroachments on floodplain water flow and cross-flow between river channels. The drainage patterns generally support the patterns observed from the 10-year flood contour mapping. One of the important items gained from this exercise is the identification of low points in the terrain, especially those at encroachments in the floodplain (Figure 6-4-7). Flood management efforts should prioritize the conservation or restoration of low elevation floodplain land areas where flood overflow would occur and recede, in order to minimize the duration of floodwater inundation of other land areas used for farming and roads.

6.4.3 Tide Gauging and Tidal Datums

▪ Objectives

The tides play a significant role in flooding and in the evolution and sustenance of estuarine ecosystems in the Tillamook Bay system. The objective of this assessment was to document available tide gauge data and to develop relationships between these recorded elevations and local tidal datums, which designate significant ecological zones in the estuary and tidal river reaches.

▪ Methods

Tidal elevations have been monitored in Tillamook Bay very sporadically since the 1920's. Up to six tide gauges have monitored water elevations in the bay, with the gauge at Garibaldi operating with the longest continuous period of record (Figure 6-4-8). Statistical data for tidal elevations for the bay are dependent on the Garibaldi gauge due to the lack of a continuous period of record for all the other gauges. The Garibaldi gauge was in operation between 1972 and 1981 and has recently been reactivated as part of a TBNEP initiative.

Monthly high and low tide elevations were obtained from NOAA for the period of record of the Garibaldi gauge. Hourly tide elevations are also available from NOAA, but these data were not used in this level of assessment. Predicted high and low tides were obtained using the nautical software Tides and Currents, version 2.5. This software provides summaries of astronomical tides. The gauged monthly high tides and astronomical monthly high tides were compared (Figure 6-4-9) to assess the magnitude and trend in differences between predicted and actual tide elevations. Predicted tide elevations were selected for those dates and times most closely matching the date and time of the gauged high tide.

Monthly high tide data were also plotted against estimated tidal stillwater elevations and the MHHW and MLLW tidal datums to assess the relationship of recorded tidal elevations to these estimated values. These tidal datums represent the average height of the high and low tides observed over a specific time interval.

Guidelines for the restoration of estuarine systems in the Pacific Northwest have been developed related to landscape principles. Two approaches consider the habitat requirements of birds and juvenile salmon (Shreffler and Thom, 1993). An example of the feeding guilds of waterbirds is shown in Figure 6-4-11, related to tidal datums. Habitat zones for waterbirds are determined by elevation, tidal inundation frequency, salinity and sediment conditions, which determine the arrangement of intertidal food organisms.

▪ Discussion

As expected, gauged tidal elevations are typically higher than predicted values (Figure 6-4-9). Elevation differences range from 3.7 feet to zero. Gauged tides have been lower than predicted tides sporadically, but in no instance have the monthly high tides been lower than the MHHW tidal datum.

In Tillamook Bay, discrepancies between predicted and recorded tides at Garibaldi may also be attributed to navigation improvements at the bay entrance and channel that possibly affect the tidal response of the bay (Levesque, 1980).

The normal tidal range within the approximately 9,000 acre bay is about 7.5 feet with this range attenuated to about 5.2 feet at the southern end of the bay, the farthest location from the channel entrance. Diurnal tide extremes of up to 13.5 feet MLLW have been recorded, with a highest observed mean tide at the Garibaldi gauge of 14 feet, MLLW (Levesque, 1980).

Although the ecological focus of floodplain and tide marsh restoration tends to be on salmon, consideration should also be given to habitat changes for other species, such as waterbirds. The use of tidal datums in restoration planning can provide a common basis from which to compare estuarine habitats and multiple species benefits.

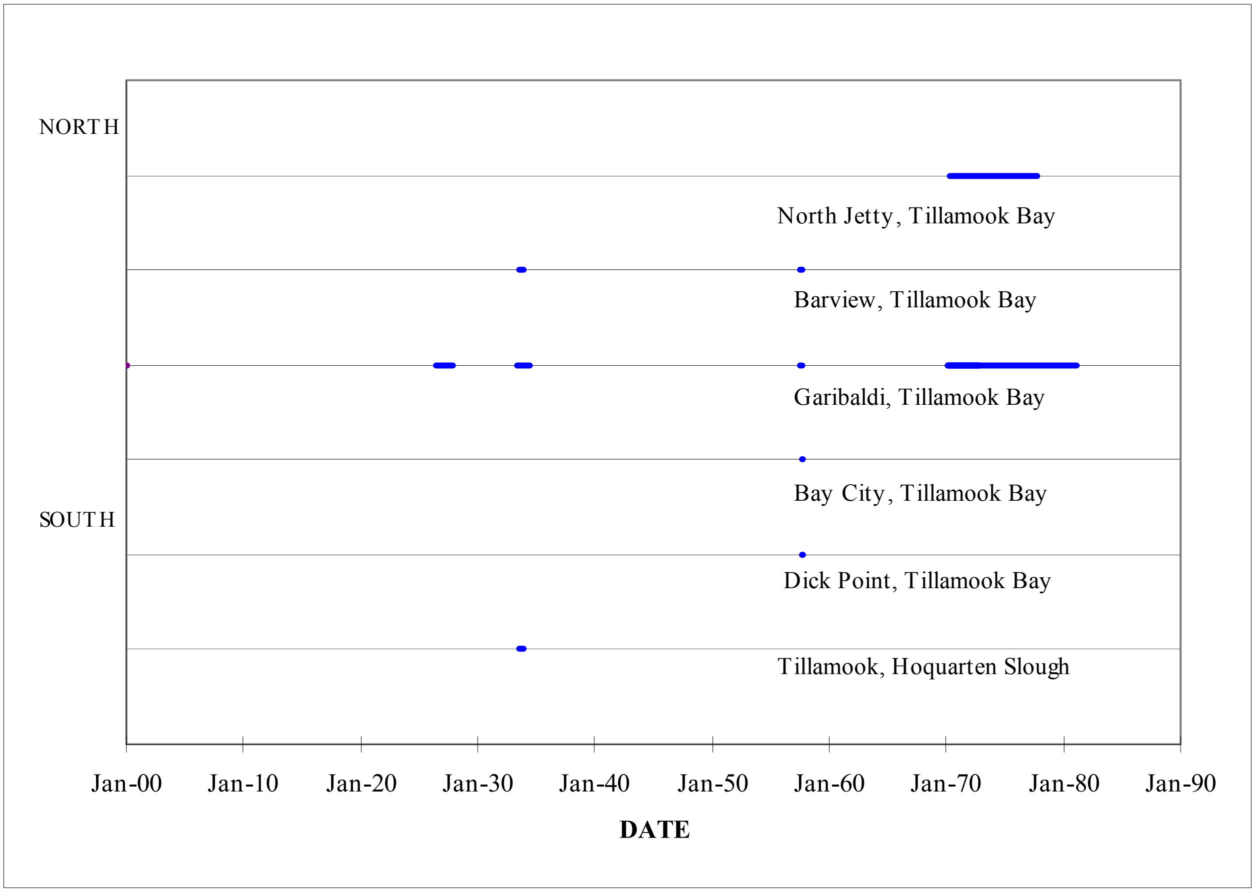

Figure 6-4-8. Periods of Record for Tide Gauges in Tillamook Bay

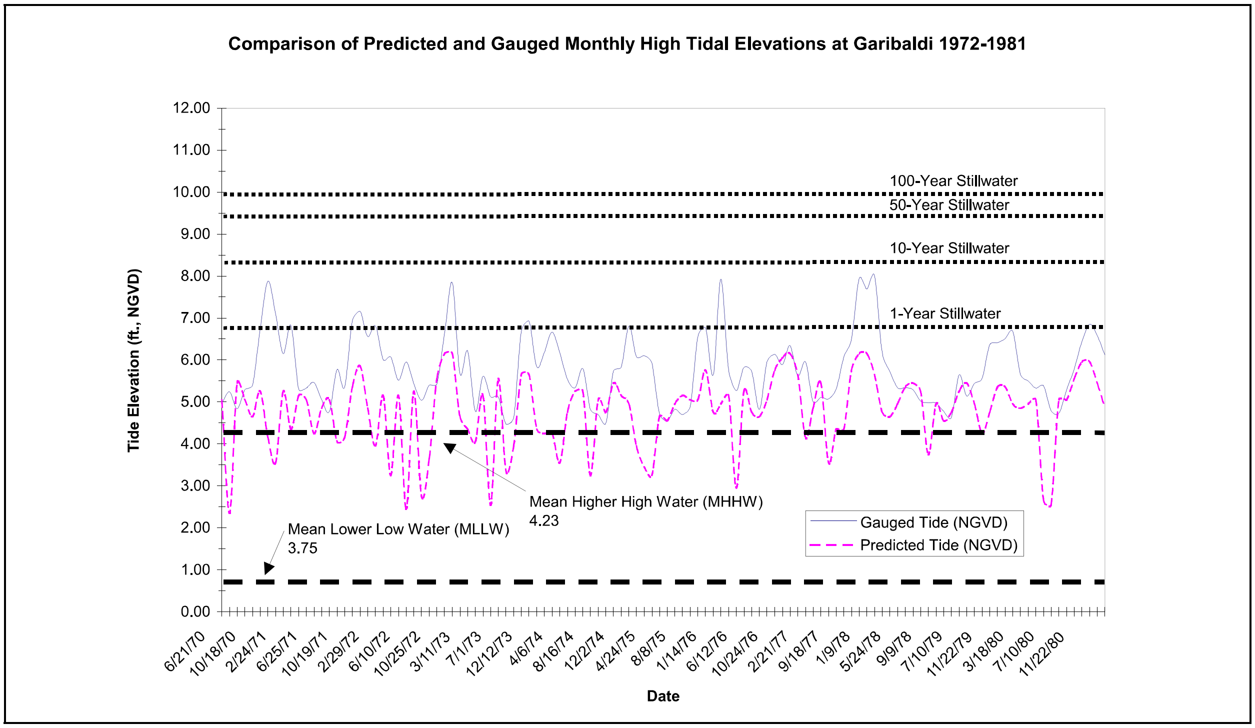

Figure 6-4-9. Comparison of Predicted and Gauged Monthly High Tidal Elevations at Garibaldi 1982-1981

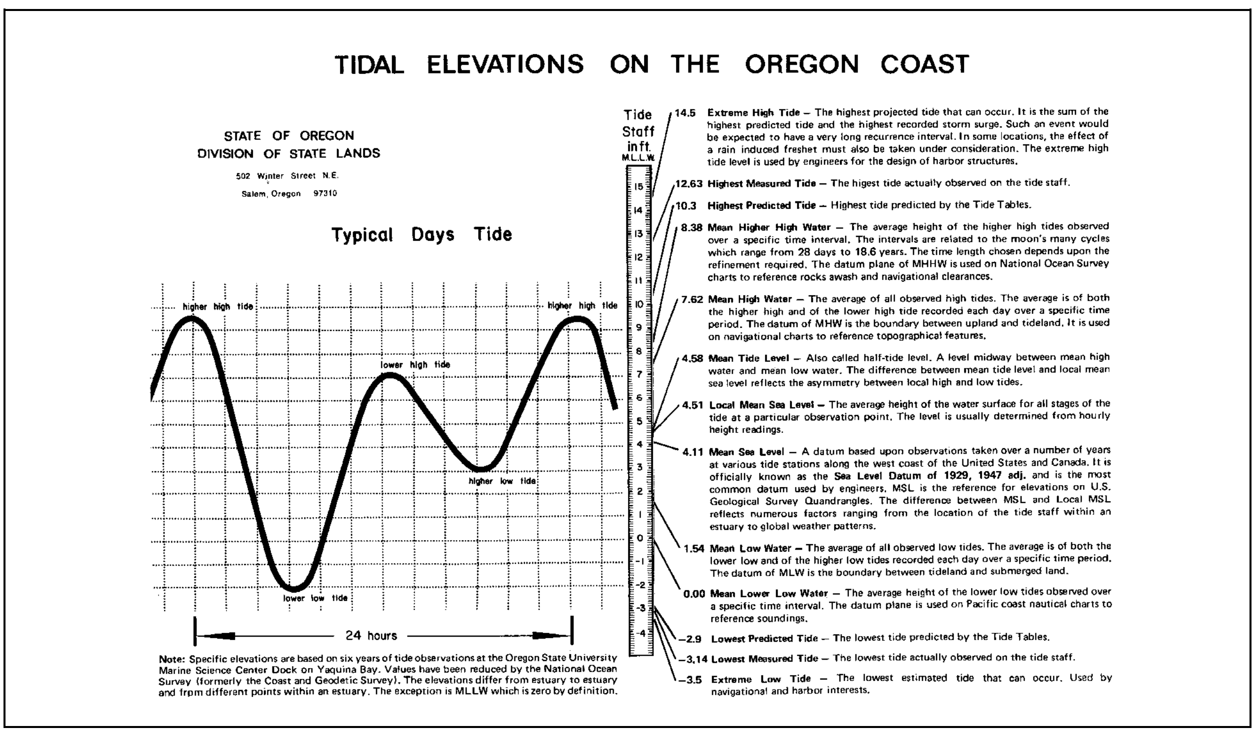

Figure 6-4-10. Tidal Elevations on the Oregon Coast Source: ODSL, 1973

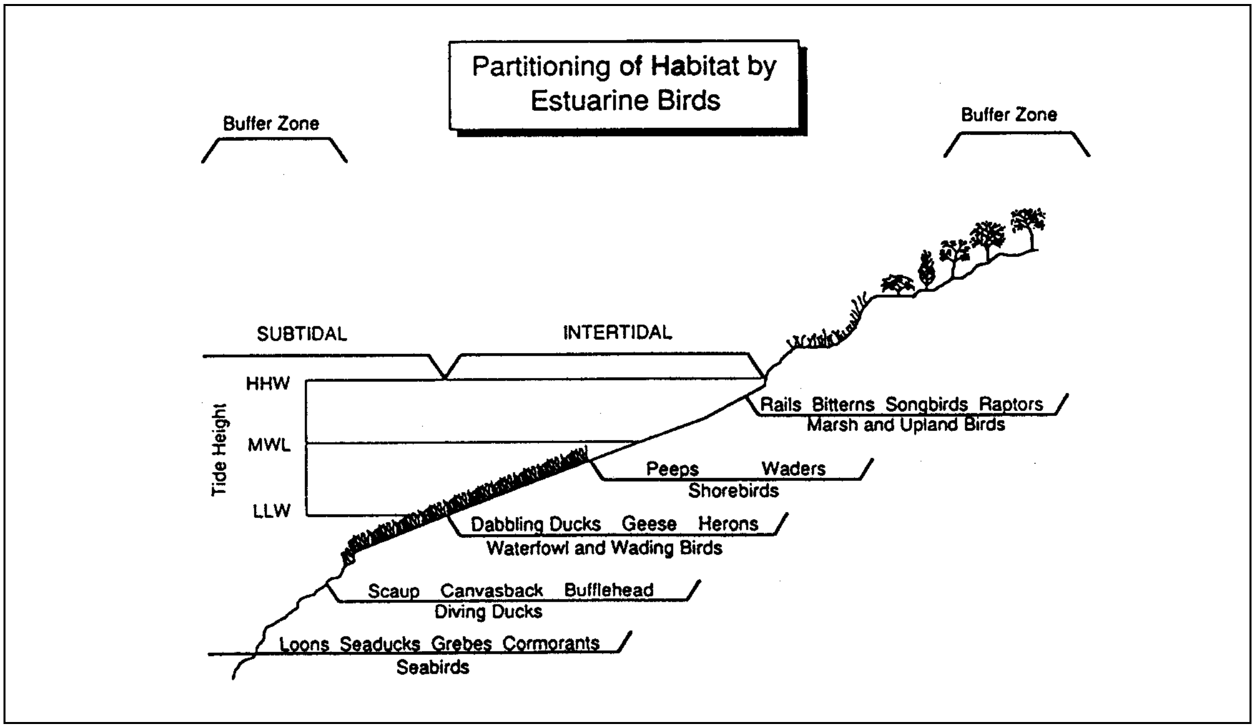

Figure 6-4-11. Partitioning of Habitat by Estuarine Birds According to Group-Specific Feeding Requirements Source: Shrettler, 1992

6.4.4 Tidal Prism Relationships

■ Objectives

Tidal prism refers to the volume of water contained between the tidal datum planes of Mean Higher High Water (MHHW) and Mean Lower Low Water (MLLW) for a given area, such as Tillamook Bay. It represents the volume of water that is exchanged during the typical half-day tide cycle. The ebb and flood movement of this volume of water provides energy to the estuary system, producing significant forces that shape the morphology of bay entrance channels--the hydraulic connection to the ocean--and tidal slough channels--the inland expression of the estuary system on the lowland valley floor. The objective of this assessment is to establish the importance of tidal prism in the management and restoration of estuary systems, and to show the relationships between tidal prism and morphological features of the estuary system.

■ Methods

Available information on tidal prism relationships pertinent to Tillamook Bay were collected to provide background for the development of management strategies for the estuary system. Figure 6-4-12 provides a schematic depiction of a tidal prism volume and its relationship to the area of a bay entrance channel below mean sea level (MSL). The relationship between tidal prism and bay entrance channel area is further illustrated for the major Pacific Coast bays, including Tillamook Bay, in Figure 6-4-13.

The tidal prism relationship to channel area and hydraulic depth (channel area divided by width) is shown for three Oregon estuaries (not including Tillamook Bay) in Figures 6-4-14 and 6-4-15.

Tidal prism relationships to slough channel morphology and marsh areas are not available for the Tillamook Bay estuary system. However, these data have been developed for estuary systems in the San Francisco Bay area and are presented in Figures 6-4-16 through 6-4-17 for reference. Tidal prism relationships to marsh area and slough channel width are useful for restoration design because these parameters can be readily determined from aerial photographs and maps.

■ Discussion

Tillamook Bay has a relatively large tidal prism compared to other bays on the Oregon coast (Figure 6-4-13). Figures 6-4-14 and 6-4-15 show trends in increasing channel depth and area, respectively, for increasing values of tidal prism. These data could be consulted if estuary management actions involve modifications to tidally-influenced channels. Modifications to channel areas and depths that fit the relationships shown may be more sustainable in the long term because the modified channel dimensions would conform to a naturally-occurring and self-correcting shape. Similarly, the design of management actions to modify or restore tidal slough channels (Figures 6-4-16 and 6-4-17) could use the general relationships developed for California slough channels as a guide, until a similar data set is prepared for Tillamook Bay or Oregon estuaries.

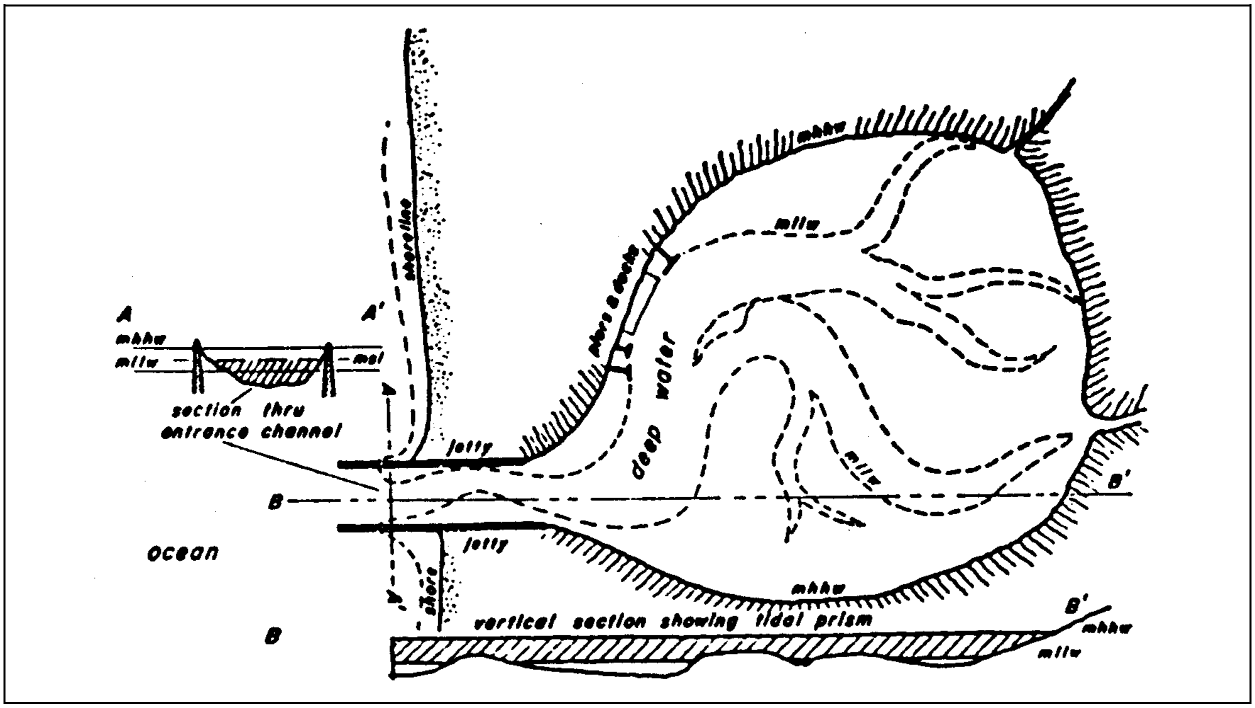

Figure 6-4-12. Bay Harbor Showing Tidal Prism the volume of water between (MHHW and MLLW Source: Bascom, 1964)

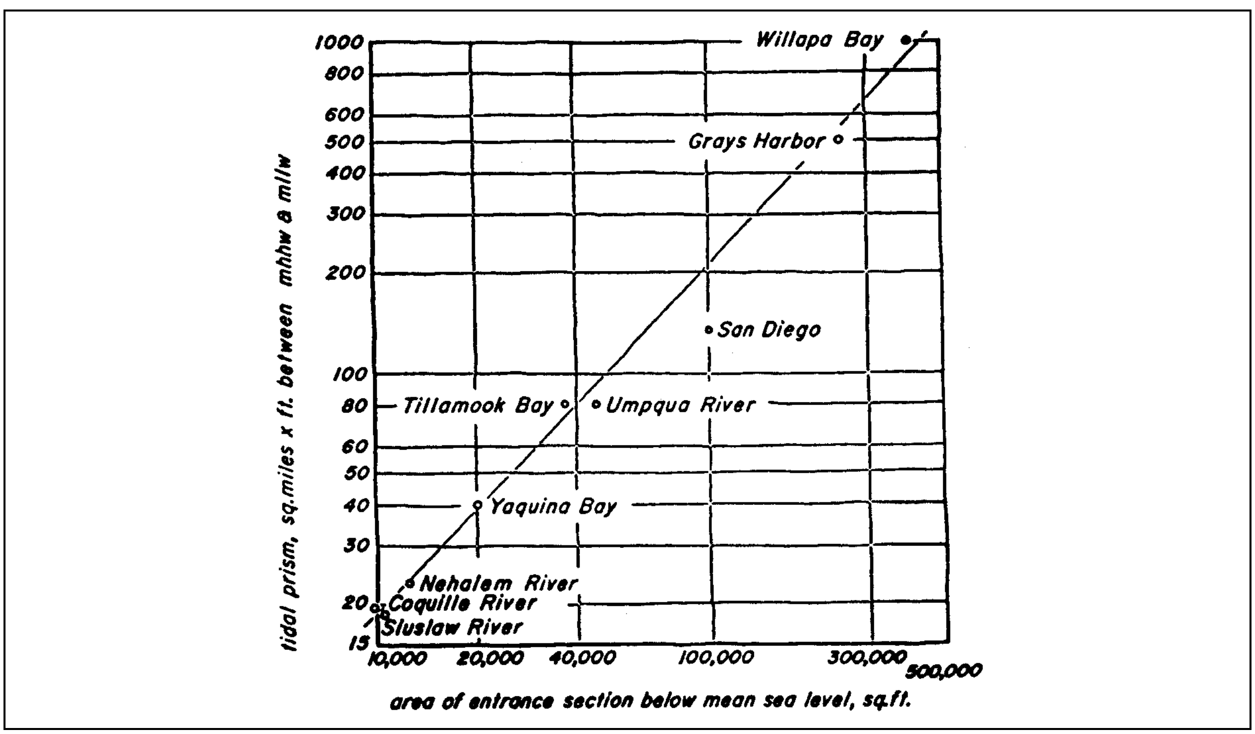

Figure 6-4-13. Relationship Between Tidal Prism and Entrance Section Source: Bascom, 1964

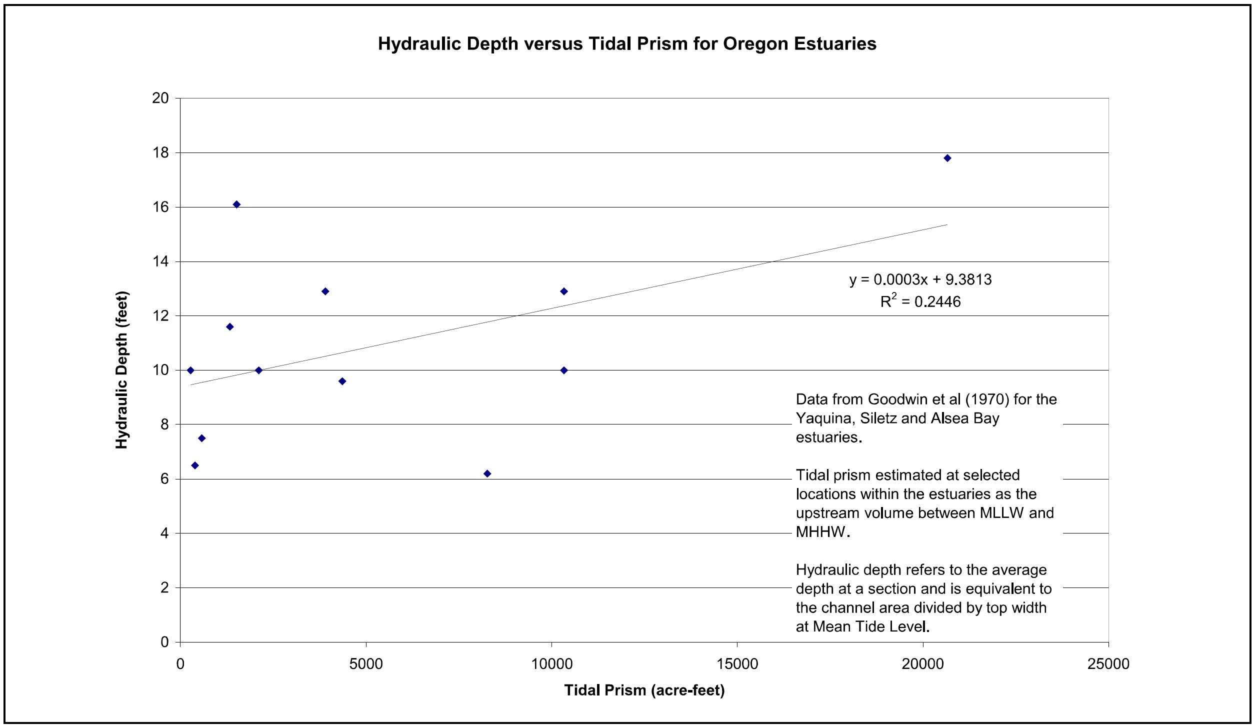

Figure 6-4-14. Tidal Prism versus Hydraulic Depth for Oregon Estuaries

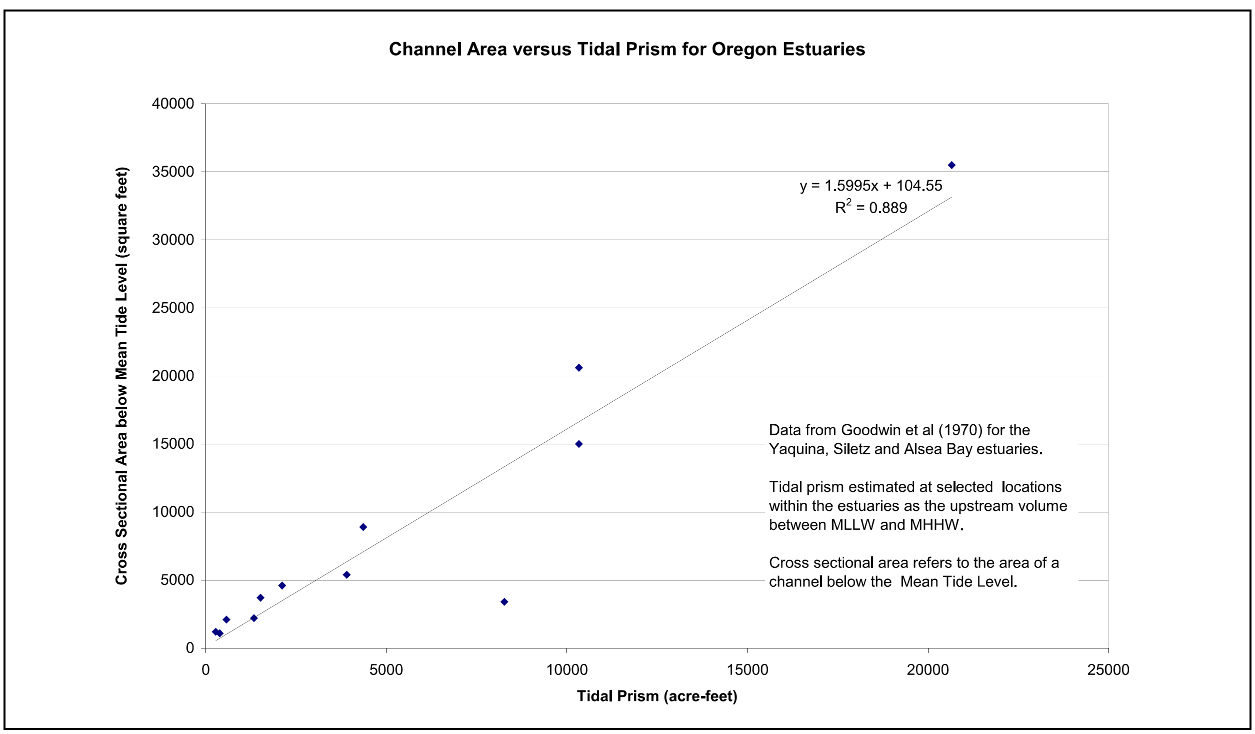

Figure 6-4-15. Tidal Prism versus Channel Area for Oregon Estuaries

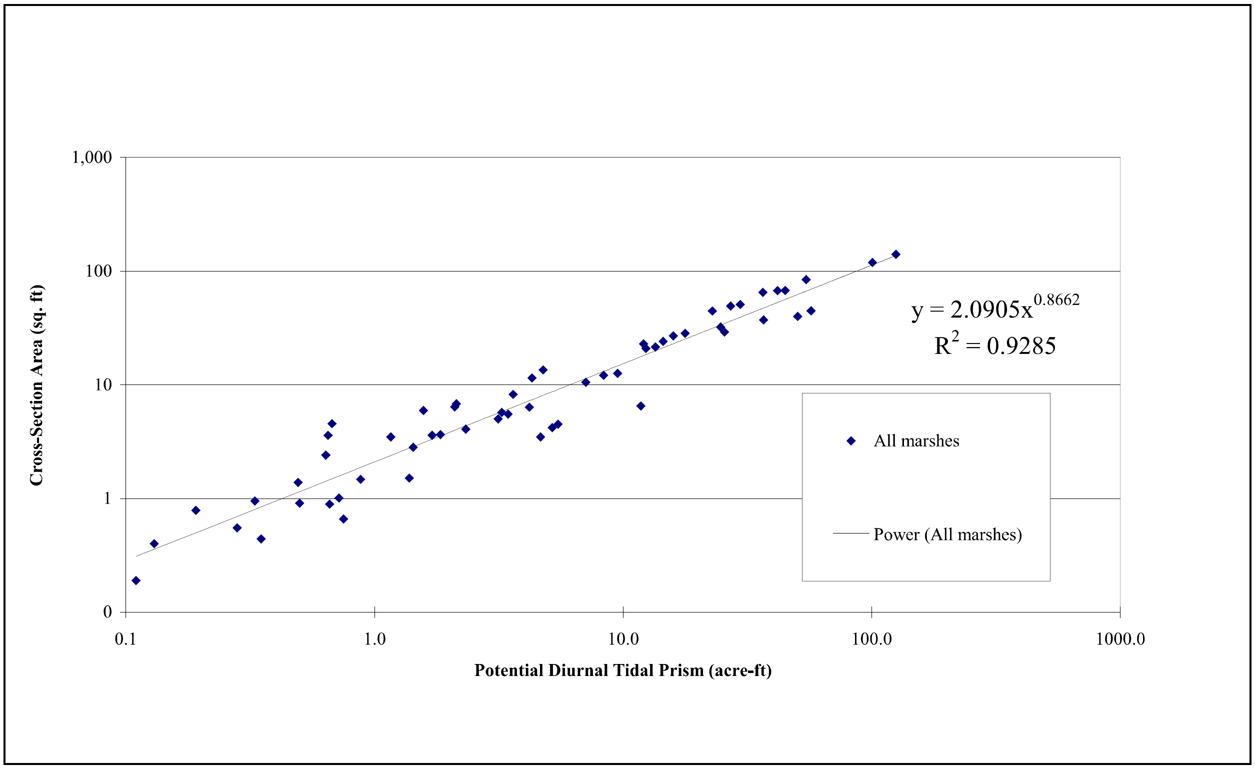

Figure 6-4-16. Tidal Prism versus Marsh Area in Tidal Sloughs Source:Coats et al., 1995

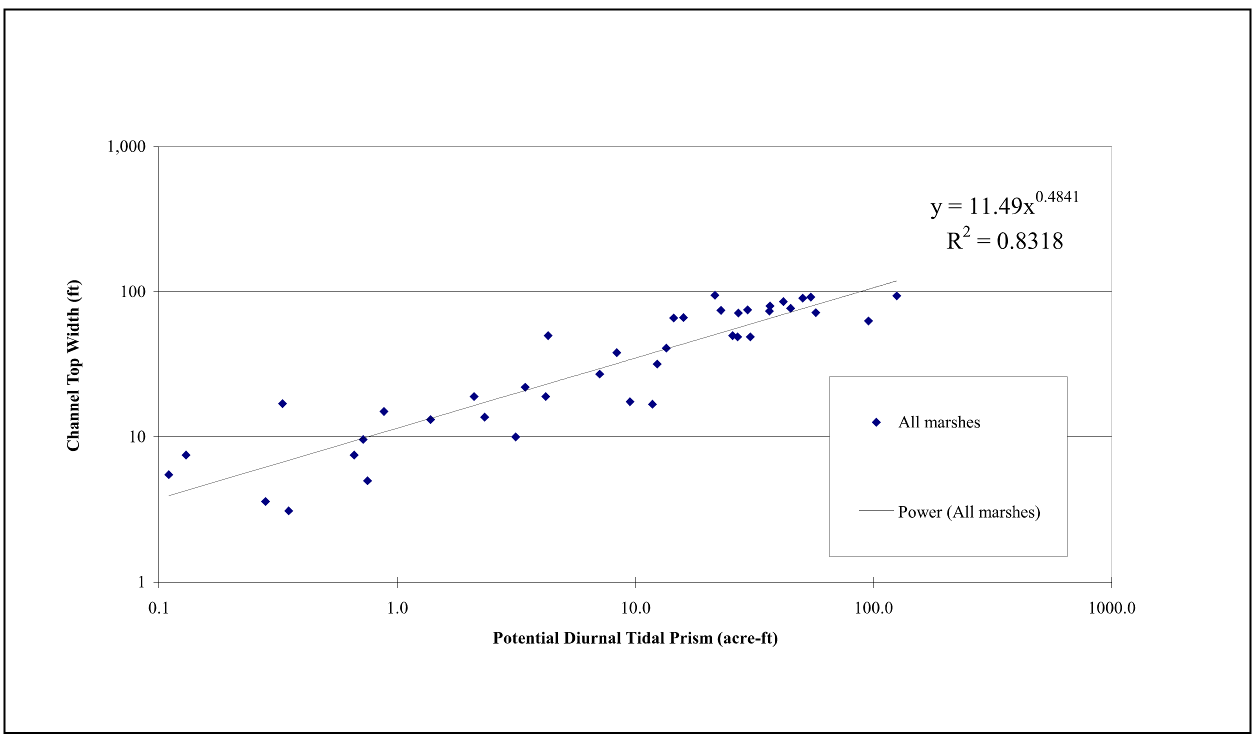

Figure 6-4-17. Channel Top Width versus Tidal Prism in Tidal Sloughs Source: Coats et al., 1995

6.4.5 Tidal River Reach Assessment

- **Objectives**

The preservation of tidal flows is important for maintaining water quality, protecting the stability of tidal channels, and sustaining tidal wetlands throughout the lowlands. Tidally-influenced areas are essential parts of the complete ecosystem of Tillamook Bay, providing habitat, refuge and rearing for several key species of fish and wildlife. Tidal influences in the lowland river reaches include tidal effects on water levels, as well as water quality effects due to salinity. The objective of this assessment is to define the spatial extent of tidal influences and to explore the relationship of these influences to a river management strategy.

- **Methods**

'Head of tide' is a colloquial expression for the furthest inland extent of tidal influence on river water surface elevation. The heads of tide for each of the five major rivers entering Tillamook Bay were identified from the Oregon Water Resources Department North Coast Basin map (Oregon Water Resources Department, 1992). Figure 6-4-18 shows the heads of tide for the Wilson and Trask Rivers.

The variation of salinity in lowland river reaches results, in large part, from the characteristics of flood tide (inland flow) and ebb tide (seaward flow), combined with river flow. During any given flood tide, the water entering an estuary is composed of a mixture of 'new' ocean water, and water which exited the estuary during the previous ebb tide and is now re-entering. This tidal exchange governs the overall flux of salinity and nutrients into and out of the river reaches and adjacent floodplain wetlands, but the distribution and concentration of salinity is strongly influenced by the mixing processes that take place throughout the system. Winds, waves, tides, and freshwater flows all contribute to the mixing of waters and help to distribute salinity within the lowland river system.

General aquatic subsystems have been defined for Oregon estuaries (Division of State Lands, 1984). In the lower reaches of the rivers, the division between brackish and freshwater subsystems has been generally located as shown in Figure 6-4-19 for the Wilson and Trask Rivers. The brackish subsystem is defined as having summer water salinities of 0.5 to 15 parts per thousand, compared to 0.0 to 0.5 parts per thousand for the freshwater subsystem (Division of State Lands, 1984).

Freshwater inflow to an estuary system provides another mixing mechanism and is a key component in estimating the boundaries of different plant community types. In addition to adding a continuously discharging flow component, freshwater flow may create density differences which result in stratification of the water column. A salt wedge may be formed which moves back and forth in the estuary with changes in tide (Figure 6-4-19), while turbulence at the interface produces mixing between the two layers. The mixing power produced by the tide depends on the density difference, the tidal velocity, the freshwater inflow and the estuary morphology, and in turn determines the density stratification which will be present in the estuary (Fischer et al., 1979). The degree of density stratification, in turn, dictates whether density-driven currents will significantly influence flows within the lowland river system. If stratification exists in the river channels and tributary sloughs, it is the lower-salinity water at the surface that flows out of the river channels and across the floodplain first, resulting in lower salinities than if the flows were fully mixed. This may be an important process if there is concern about maintaining a particular salinity range to favor or discourage certain types of plant communities.

Tillamook Bay is classified as a partially-mixed estuary (Fischer, 1989), where river flow discharges against a moderate tidal range (The Open University, 1989). Mixing of the water column is induced by turbulence created at the saltwater-freshwater interface and by friction along the bed of the bay and river channels. Additional mixing processes occur through wind and through circulation patterns in the Bay and tidal channels. A detailed description of these processes is provided in the literature, for example Fischer *et al.*, 1979, or the Open University, 1989. An illustration of water velocities and salinity concentrations in a typical partially-mixed estuary is shown in Figure 6-4-19. This figure also illustrates one reason for maintaining the natural geomorphic characteristics of tidal channels. If levees are constructed adjacent to the channels, or if the marshplain is filled, the flows over the marshplain may divert only surface waters, which will be fresh under stratified conditions. Under a different channel cross-section, the high tide may allow a mixture of fresh and saline water to flow across the marshplain. Thus, salinity structure and mixing processes are complex, influenced by river discharges, tidal flows, geomorphic characteristics of the tidal channel, and dominant physical processes. Prediction of hydroperiod and salinity in tidal channels and wetlands requires monitoring and/or the use of computer models.

■ Discussion

The significance and continuing loss of tidal wetlands in the western states has been well documented (Cowardin et al., 1979, Salveson, 1990 and Fretwell et al., 1996). The importance of taking a long-term planning perspective of tidal wetland preservation can be seen when considering the effects of sea-level rise (Houghton et al., 1990). The natural response of tidal wetlands to a sea-level rise would be to gradually migrate inland (French et al., 1995; Nuttle et al., 1997). However, if tidal channels have levees at their banks, there is no room for tidal vegetation zones to retreat. Further, the depth of the tidal channel cross-sections would be expected to gradually increase over time, resulting in bank stability problems. Planning to allow a buffer adjacent to tidal channels would therefore avoid channel stability problems and maintain some minimum acreage of intertidal habitat.

The tidally-influenced areas of the Tillamook Bay tributaries are the most dramatically diminished habitat type in the Tillamook watershed. These areas provide critical rearing and refuge habitat to several ESA-listed fish, and other organisms essential to the sustainability of the ecosystem. Functioning properly, they are likely to produce the most biomass per unit area (Tiner et al., 1984) of the entire basin, and form an important ecological link.

These tidally-influenced areas also correspond with some of the most expensive flood damages and channel protection activities, and highest revenue generated per unit area, in the basin. Restoration of these areas could provide several key flood reduction benefits for the people of Tillamook County, including:

- Diffusion of flood flow energy
- Reduction of wave action against levees and banks with the use of shallow vegetated buffers
- Improvement of water quality by removing nutrients and fine sediments

These tidally-influenced areas should therefore be prioritized for implementation of the IRMS, for both ecological and economic reasons.

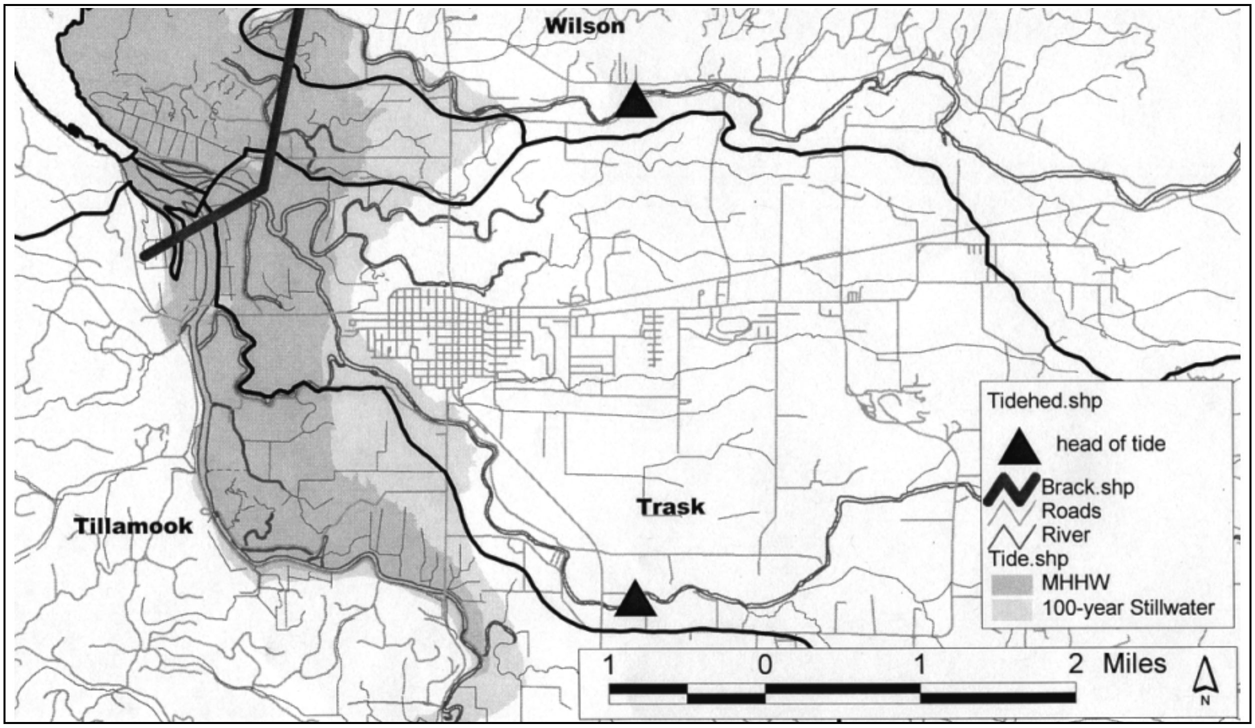

Figure 6-4-18. Tillamook Bay Lowland Valley Heads of Tides and Brackish/Freshwater Interfaces

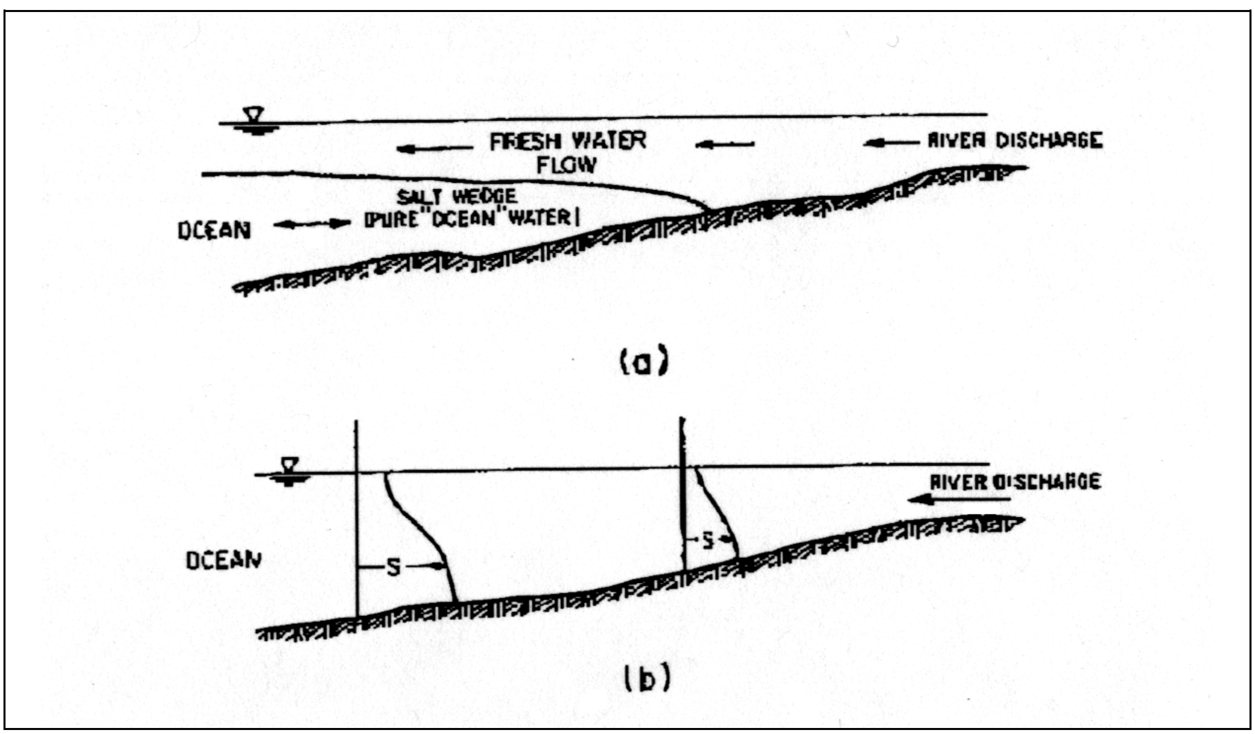

Figure 6-4-19. Salinity distributions in (a) a "salt wedge" estuary and (b) a "partially mixed" estuary