VARIATIONS IN ALSEA RIVER FLOW; IMPLICATIONS FOR ALSEA SPIT & INLET STABILITY

by

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CONTENTS

FIGURES

TABLES

ABSTRACT

Based in part on previous work by this researcher, variables assumed to play a minor part in the process/ response system examined by the OSU Alsea Bay Hazard Study Team (1985-87)--river input and subsequent variations in hydrology--were more completely analyzed for their range of effects on the stability of Alsea Bay Spit and inlet. Through air photo analysis of spit configurations, compilation of concurrent tide prism characteristics, and empiric study of environmental variables, a correlation matrix was developed to refine and evaluate the parameters used in determination of stability for the spit and inlet. Results of the statistical analysis showed high correlation between spit area, tide range, and tide prism variations. No significant correlation was found between river flow and spit size, except when flow is combined with total tide prism volumes. These findings provide the basis for further development of a predictive model capable of identifying future unstable periods at the Alsea Bay inlet.

INTRODUCTION

During the late fall and early winter of 1985, the sand spit then extant at the mouth of Alsea Bay, Oregon began to rapidly erode due to a dynamic imbalance in the processes responsible for its formation (Figure 1). Within a two-week period the spit had eroded northward as much as 400 meters,

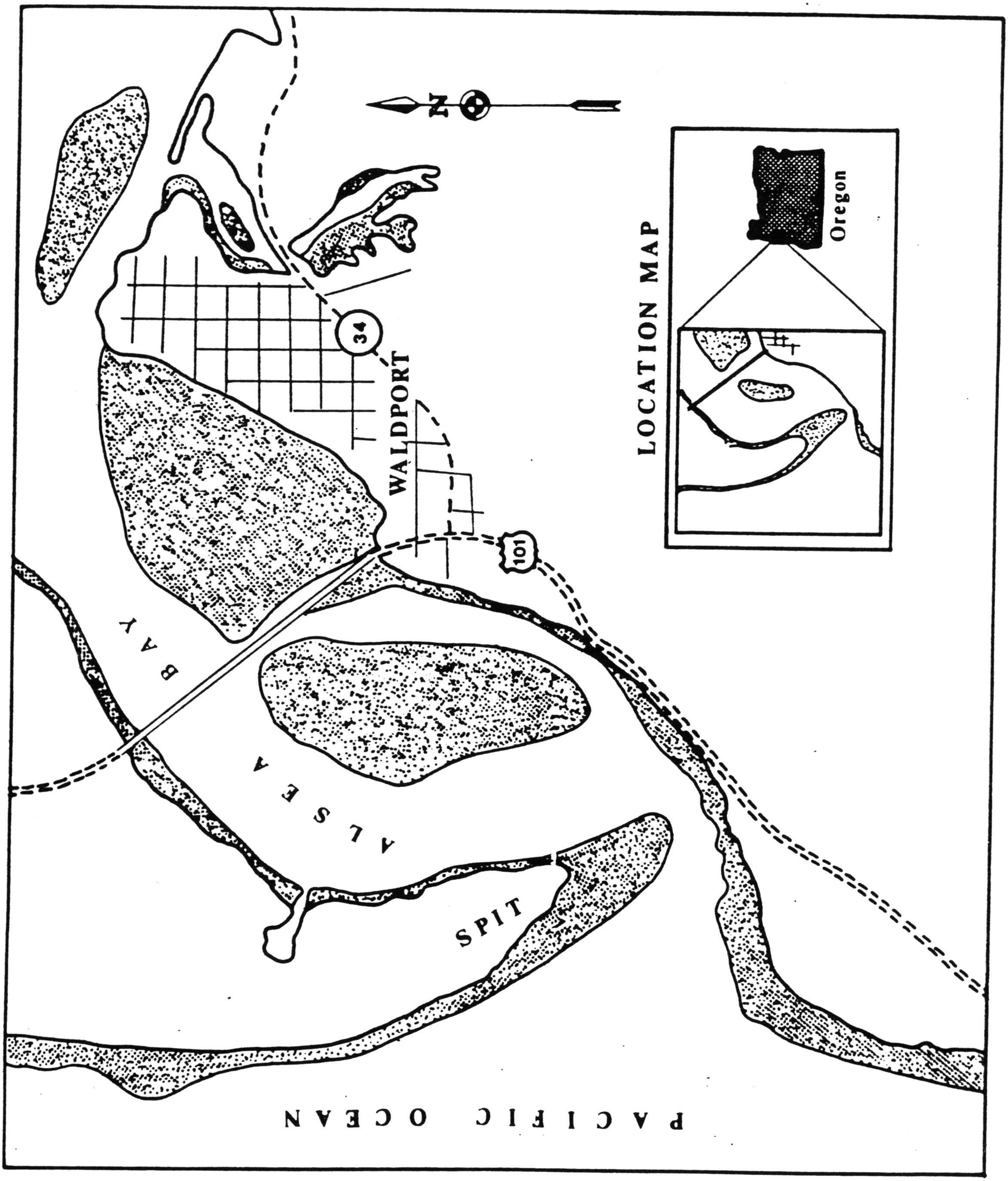


Figure 1. Location Map.

reportedly increasing the bay mouth cross-sectional area almost 400% (Jackson et al, 1986). This increase in bay mouth area created three immediate hazards: one, the loss of the spit as a barrier would allow direct wave attack on the low lying city of Waldport; two, the mean tidal elevations in the bay could rise an additional .6 meters due to the decreased hydraulic constriction at the bay mouth, creating the potential for increased flooding; and three, the continued northward erosion of the older, more stable, spit formation could eventually undermine a dozen or more unprotected residential structures located there.

The above-mentioned hazards led the city of Waldport and the Lincoln County authorities to seek state and federal aid under the guidelines of the Federal Emergency Management Act (FEMA). Before any FEMA authorized mitigation of the hazard could take place however, the extent, severity and potential increase in flood and wave hazard needed to be assessed. It was at this point in time that a Hazard Mitigation Team was assembled from Oregon State University's Department of Geography and School of Oceanography. Research was aimed at monitoring the bay mouth configuration, determining the amount of change in tidal dynamics, determining the potential causes for the erosion at the spit, reassessing the potential for flooding in the Waldport area, and finally, making recommendations for both structural and nonstructural mitigation of the hazard.

The results of the study team's analyses were published in July, 1986: Assessment of Marine and Geologic Hazards at Alsea Bay, Oregon. This report concluded that the forcing agent responsible for the erosion was probably the El Nino event of 1982 - 83 which produced an anomalous northward shifting of sand in the littoral cell (Jackson et al, 1986; Komar, 1986). It was reported also that the immediate threat to Waldport could best be mitigated by a sea wall serving as both a flood control and wave absorption structure. Even though the U.S. Army Corps of Engineers (COE) accepted the report findings in principle, they ruled against construction of the dike on the grounds that it provided too permanent a solution to fall under their emergency mitigation criteria, and, that there was no way to predict the recurrence interval of storms effecting marine floods and increased wave attack (COE, 1986). Since the publication of the OSU report the COE has included a structural remedy for future erosion events in their five year plan; a sea wall along the area most prone to wave attack.

Although the initial Alsea Bay study was concluded with the published report (Jackson et al, 1986), continued research at the bay mouth and spit was funded an additional year through Sea Grant in order to better document the processes effecting the spit's configuration.

DEFINITION OF THE OBJECTIVES

The primary aim of this research paper is to further document one of the variables previously assumed to have minor input to the process/response system shaping the configuration and stability of the Alsea Spit and inlet. A correlation of variations in hydraulic capability through the inlet with erosion periods was not evaluated in the initial study. Expanded research into the climatic cycles impacting the region and the resultant effect on river hydrology was therefore undertaken to better define those variations and effects. The rationale behind the expanded research lies in the general Hazard Research Paradigm. That is, to assess key variables related to the threat, including inputs to the process/response system that create the perceived threat (White,1975; Visvader and Burton, 1974).

Periodic variations in storm activity along the Oregon Coast appear to follow a significant, if somewhat unpredictable pattern. This cycle has a period of approximately 7 years from peak activity to peak activity (Fox and Davis, 1978). This research aims not to confirm that cycle, but to evaluate its range of fluctuations in hydrology induced by precipitation for the Alsea drainage basin and to view its correlation with erosion events at Alsea Spit.

Understanding the stability characteristics of the inlet at Alsea Bay is a major focus of this report, so it follows that refinement of the inlet stability equation using current data is required to determine if variations in spit stability correlate with inlet configuration.

Included below is a review of assumptions used in the Alsea Bay inlet stability calculations (Jackson et al,1986); the results of an ancilary study of preliminary flow data for the Alsea River (O'Neil,1986); and additional background for environmental assumptions used in this paper.

Research Questions

This paper poses the following research question: Does a significant correlation between Alsea River flow and Alsea Spit erosion events exist?

A problem arises when attempting to isolate the exact hydraulic variable, if any, that could be considered the principal factor governing erosion. The time lag that occured between the 1982 - 83 El Nino/Southern Oscillation (ENSO) event and the loss of the spit in late 1985 shows that in attempting to correlate erosion with flow, a problem of temporal scale may arise. Examining the research question using data from the first flow analysis (O'Neil,1986) showed that attempting to correlate low flow and erosion events was not the most comprehensive way to approach the problem. Logically, higher river discharge would require additional cross sectional area for stability, and, greater hydraulic capacity of the inlet would result in an erosive loss of spit area.

It is assumed here that the erosion event is the manifestation of an imbalance in the processes responsible for the stability of the spit and inlet. Using the refined stability equation described in the methodology section, actual river discharge volumes were used to determine the inlet cross sectional area required for stability.

Alsea Bay Study Team

The stability equation used in the 1986 report utilized spring tide volumes for analysis, assuming away the effects of river input to the system. While this method, originally outlined by O'Brien (1969), has been used in many inlet configuration studies (Jarrett, 1976; Watson and Behrens, 1976; Escoffier, 1977), the inclusion of hydraulic variations due to river flow input is possibly important (Bruun and Gerritson,1960.). This is due to the effects of density currents, as well as added hydraulic head of the concurrent discharge during spring tides. Indeed, the OSU study team alluded to the increase of river flow assisting in the reestablishment of the normal inlet configuration (Jackson et al, 1986). It was further assumed that an erosion event of this magnitude was a discrete event. The photographic evidence compiled supports this assumption generally; however a more complete chronology of recent aerial photos reveals the more dynamic nature of the spits growth and decline. Aerial photos shows the 1984 spit configuration to be one of the largest on record, not the average. This suggests that the spit configuration has changed more frequently over time than originally thought.

Additionally, several of the assumptions made for the adjustment parameters required in O'Brien's stability equation (1969) have been changed in this paper to reflect more current data. These parameters, including bay area, tide range, and coefficients, were adjusted for this analysis. This is discussed more in depth later in this report.

1986 River Flow Study

The OSU Study Team during the first year of research discussed the idea of flow variation as a factor in spit configuration. The available river stage data was compiled in an attempt to verify any anomalous flow related to the 1985 spit erosion event. It was thought that low river flow might contribute to destabilizing the inlet configuration by lowering the hydraulic capability of the tidal prism, resulting in a filling in of the typical south inlet channel. Statistical analyses of the minimum, maximum and mean flow rates were completed. Those analyses were used in part for a Quantitative Methods (Ggs 561) research paper, as well as a paper presented to the Oregon Academy of Sciences 1987 annual meeting (O'Neil, 1986;1987). It was concluded that no significant correlation existed between flow levels and erosion events. The data set used for those studies, though useful, was not yet complete. It was also concluded that more complete information on erosion events and river input was required before any statements about their effects could be made (O'Neil, 1987). The following methodology outlines the procedures taken to address the questions presented above.

METHODOLOGY

This section describes the techniques utilized to evaluate the variables used in assessing the impact of river flow on the stability and configuration of the Alsea Spit and inlet. Examination of aerial photos was undertaken to determine spit areas. River stage data were used to find the mean and maximum flows entering the bay, allowing its contribution to the tidal prism to be considered. Adjusted parameters of O'Brien's stability equation and a new estimate of bay area were used with the river flow data to help refine the calculations of inlet stability. Variations in river flow and its contribution to the tide prism is described, followed by a statistical analysis of the effects of tide range, tidal prism, and river flow on spit configuration.

Identification of Erosion Periods.

The air photos used in the initial flow/erosion correlation were analysed for their Area Ratios (A/R). This means that using the 1984 spit configuration as an assumed standard, each air photo was measured for relative spit area. An A/R <50% of normal was considered a extreme erosive event. This was then correlated against the mean, maximum and minimum flows for that same year (O'Neil, 1986). For this study, the original 1939 - 1985 photo series developed in the 1986 study was augmented with others from 1961 - 1985, and all spit areas (Figure 2) were measured using a digitizer. The years covered by the photos were used because they coincided with the hydraulic data already compiled. Prior to digitizing the spit areas a reference line was drawn from the southern base of the Highway 101 bridge, across to a common point located on the more stable portion of the spit formation. This helped to delineate the most active portion of the spit for comparative study. The additional photos helped to establish a more complete chronology of erosive events, a method considered essential for a historic view of erosion periods (Fulton, 1981). Analysis of the air photos for the given period resulted in the data listed in Table 1, and graphed in Figure 3. These numbers are the actual spit areas determined by the previously described method and are used in the correlation matrix in the following section.

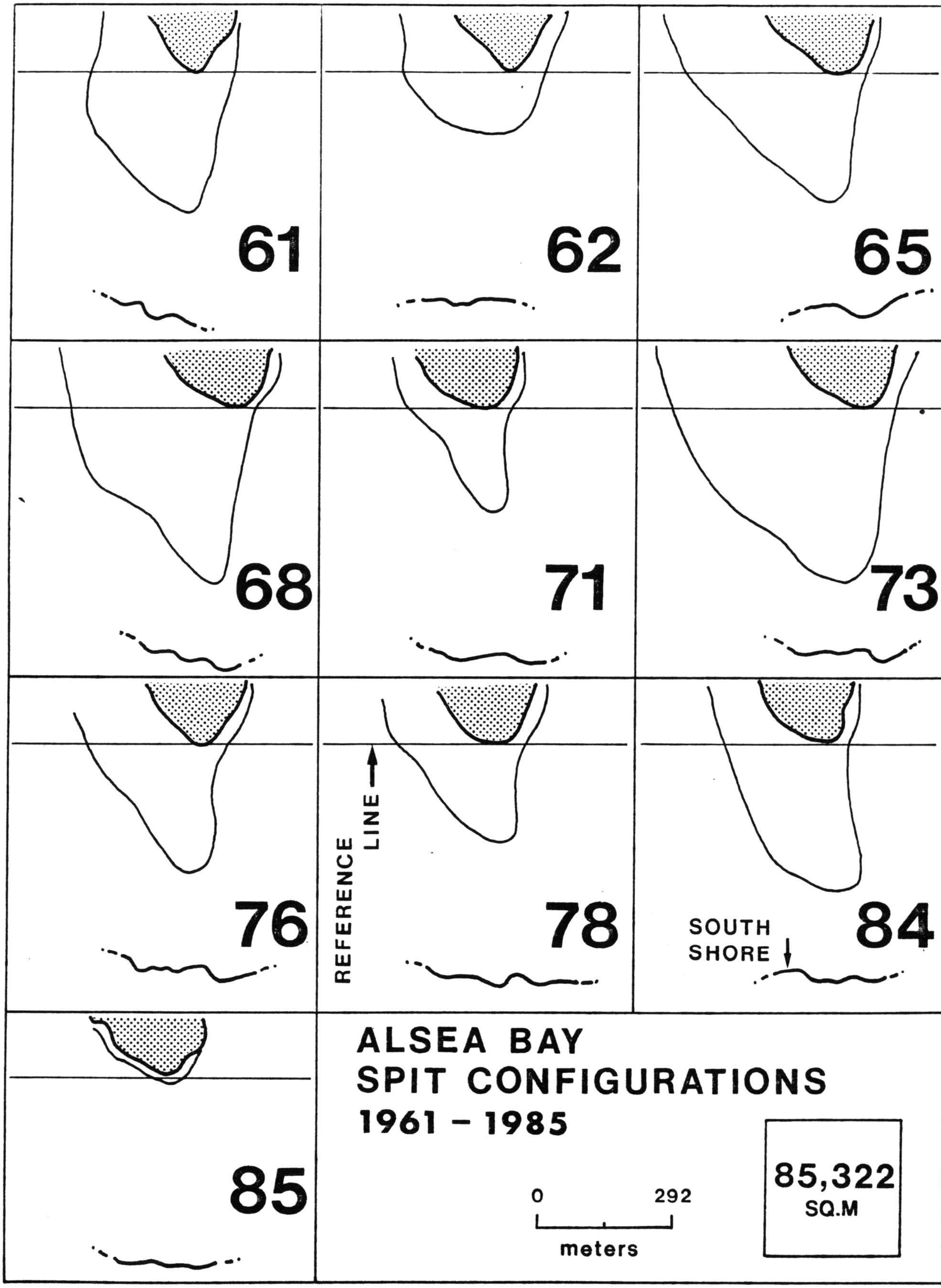


Figure 2. Spit Configurations.

Table 1. Spit Areas.

YEAR	SPIT AREA (M^2)	DEVIATION FROM MEAN (M^2)	SD
1961	66,643	15,682	+.385
1962	33,321	-2,193	-.739
1965	64,912	9,678	+.326
1968	89,681	34,447	+1.163
1971	24,769	-30,465	-1.028
1973	121,283	66,049	+2.230
1976	47,830	-7,408	-.240
1978	33,310	-21,924	-.740
1984	66,620	11,386	+.384
1985	768	-54,466	-1.838
	MEAN 55,234	SD = 29,618	

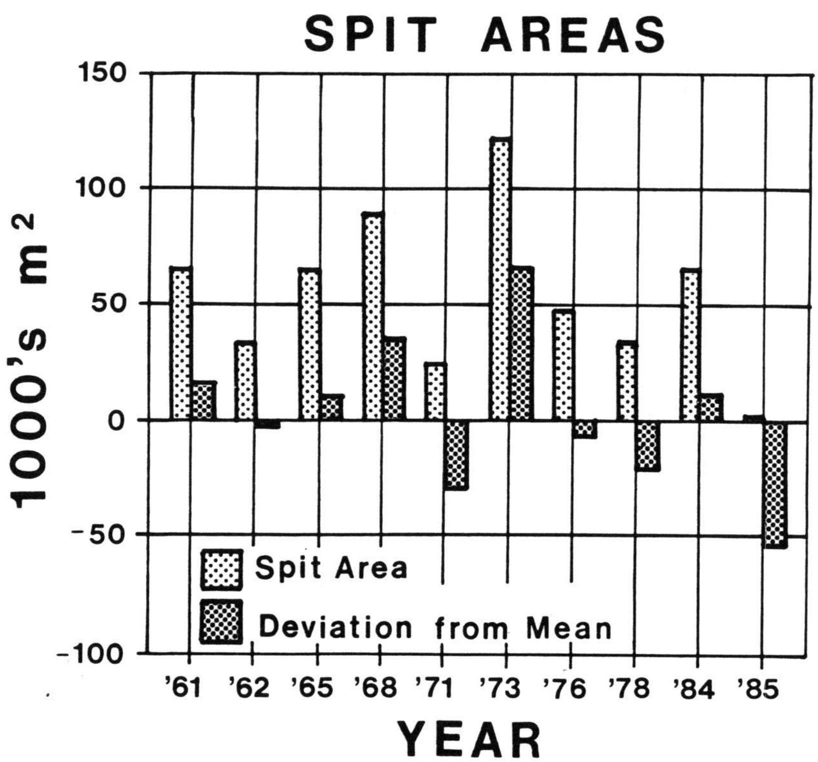


Figure 3. Spit Areas.

River Flow Variations.

The river flow data originally compiled were entered into the Statistical Processing System (SPS) for the Apple II, along with additional flow data to cover the extended period of the air photos. Flow data were taken from River Stage Reports published primarily by U.S.G.S (1955 through 1985). Because of the time lag between the last ENSO event and the erosion in 1985 the flow data were grouped into 3 classes relative to the identified spit configurations: one, the discharge (Q) two years prior to the event; two, Q one year prior to the event; and three, Q for the same year as the event.

Establishing Stability Parameters.

As mentioned in the background section, bay surface area, tide range, and, O'Brien's variable coefficients were reexamined to refine the inlet model calculations.

From current literature the variables of b and N for O'Brien's original stability equation adjusted for west coast inlets were input to the formula. This formula is shown in the results section.

Bay surface area was determined from a map of the Alsea Bay estuary obtained from the Oregon Division of State Lands. This relatively large scale map, 1:12000, has the mean high water line for a shore line so it could be used in the determination of high tide bay area. The equation was adjusted using the actual maximum tide range predicted for the Waldport area as determined from tide tables (US CGS. 1959 through 1985) instead of the spring tide range (see appendix 2). As with the air photos used to determine spit area, the years covered in Appendix 2 coincide with river discharge data available for this analysis. This approach more accurately portrays the yearly fluctuations in spring tide prism values (Watson and Behrens, 1976). The mean yearly discharge of the Alsea River (Table 2, next page) was added to the tide prism values for each year covered and should provide a more accurate estimate of potential hydraulic head.

Refinement of the Stability Equation

The relative stability of the Alsea Bay inlet using O'Brien's original equation is as follows:

$$Ac = b\ P^{n}$$

Where Ac is the cross-sectional area at stability, b and n are conversion functions, and P is the tidal prism calculated at spring tide. The OSU study utilized these values in their assessment;

$$b = 2.0 \times 10^{-5}\ ,\ P = 2.2 \times 10^{8}\ ,\ n = 1$$

This equation has been empirically adjusted for use on the west coast (Jarrett, 1976). Jarrett found that for unjettied west coast inlets the values for O'Brien's b and n are 1.91 and 1.10 respectively.

The bay area value computed in the manner described was found to be 9.4×10^6 m^2, compared to an area of 8.0×10^6 m^2 calculated in the 1986 study (Jackson et al, 1986); the average maximum tide value is estimated at 3.0 m (see Appendix 2). The stability equation can then be worked adding a new tide prism value with the following results.

$$Ac = 1.91 \times 10^{-6} \times 6.33 \times 10^{9}$$

$$= 12.09 \times 10^{3} \ ft^{2}$$

$$= 1124 \ m^{2}$$

Table 2. Flow Data.

Mean Yearly Flow					
Water Year	CF/S	CM/S	Water Year	CF/S	CM/S
1959	1331	37.67	1971	2067	57.88
1960	1603	44.88	1972	1658	46.42
1961	1800	50.40	1973	1675	46.90
1962	1286	36.00	1974	1804	50.51
1963	1383	38.72	1975	1628	45.58
1964	1792	50.18	1976	1008	28.22
1965	1247	34.92	1977	1099	30.77
1966	1516	42.45	1978	941	26.35
1967	1333	37.32	1982	1857	52.00
1968	1765	49.42	1983	1930	54.04
1969	1374	38.47	1984	1669	46.73
1970	1691	47.34	1985	1220	34.16

Contributions of river flow

Related to the hydraulic head of the tidal prism is the volume of water contributed by the Alsea River. From Table 2, a mean annual flow of 1572 cfs only adds an additional 3.1% to the total volume during the 6 hour (21,600 sec) tide period. The mean monthly maximum river input, however is much greater, ranging between 9.24% and 10.4% additional volume. Individual discharge events, though not covered in this report, have the potential of increasing the total tide prism significantly. For example, a river discharge of 20,000 cfs--not uncommon during winter months for the Alsea River--adds 4.53×10^8 ft^3, a tide prism increase of 45%.

For the correlation matrix discussed below, the mean yearly discharge during the tide cycle was included to determine the average maximum tide prism.

River Flow Correlation with Erosion Events

Using the relative spit areas, river flow data, and total tide prism data for each year covered by air photos, a correlation matrix was developed. The data were normalized (base E log) prior to input because flow data does not follow the normal curve: discharge does not go below zero (Shaw, 1985). The results are seen in Table 3.

Pearson's r with an n of 10 requires a value of .549, .632, and .715 for significance at the .1, .05, and .02 level, respectively. The correlation matrix reveals that strong statistical correlation exists, .713, between the predicted maximum tide range and the spit area. The tide prism to spit area correlates above the .05 level, .648, but not as well as maximum tide to spit area. Results of the T test are similar.

Table 3. Correlation Matrix (Pearson's r).

Variable:	SPIT	MAXT	PRSM	FLOW	FLOW+1	FLOW+2
SPIT	1	-.7134	-.6489	-.2792	.1811	.0462
MAXT	-.7134	1	.9465	-.0543	-.0372	.1837
PRSM	-.6489	.9465	1	.2348	.1976	.3382
FLOW	.2792	-.0553	.2348	1	.8866	.7138
FLOW+1	.1811	-.0372	.1976	.8866	1	.9151
FLOW+2	.0462	.1837	.3382	.7138	.9151	1

SPIT=Spit area

MAXT=Ave.max.tide range

PRSM=Adjusted Max. tide prism

FLOW=Mean yearly flow

FLOW+1=Flow + prev. year

FLOW+2=Flow + 2 prev.years

DISCUSSION

The refinement of the stability equation has allowed a more accurate analysis of the dynamics at work within the Alsea Bay inlet. With the apparent range in inlet cross-sectional areas required for stability, fluctuations in spit configuration can be seen to follow the variations in the major factors of this process/response system--tide prism and river flow inputs to the prism.

The correlation between spit size at the Alsea Bay inlet and the fluctuations in tide and river flow governed tide prism should lead to more detailed analysis of both the climatic input and the fluctuations in tide ranges. This could lead to a predictor model capable of identifying future unstable periods at this and possibly other west coast inlets.

The tidal constriction, based on the new cross-sectional area data, is probably less than that determined in 1986. This is based on the bay mouth morphology as determined during January and February 1987. The inlet configuration was determined using bathymetric data and exposed spit topography (Figure 4.). The cross-sectional area of the inlet at that time was approximately 1000 m^2.

Shortly after that morphometry was completed an analysis of the actual tide range within the bay was undertaken. Three tide cycles between February 17th and 18th were monitored to determine the actual constriction at that time (Figure 5.). The resulting analysis of relative change in bay-water level showed an average constriction of .90.

While the mean annual river flow contributes an average of only 3.2% of the tidal prism and mean monthly maximum flow from 9.24 to 10.4%, this volume should not be over-

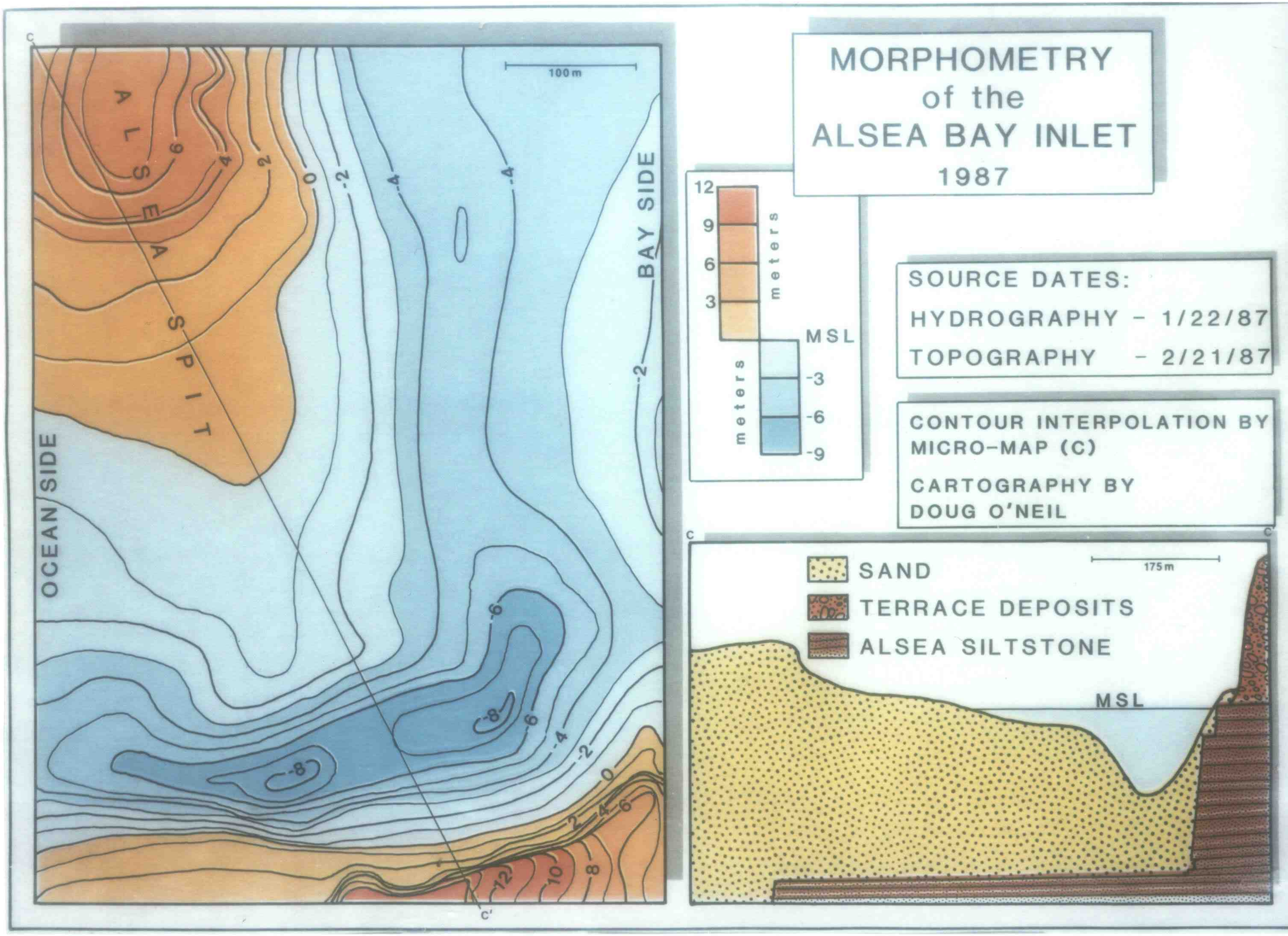
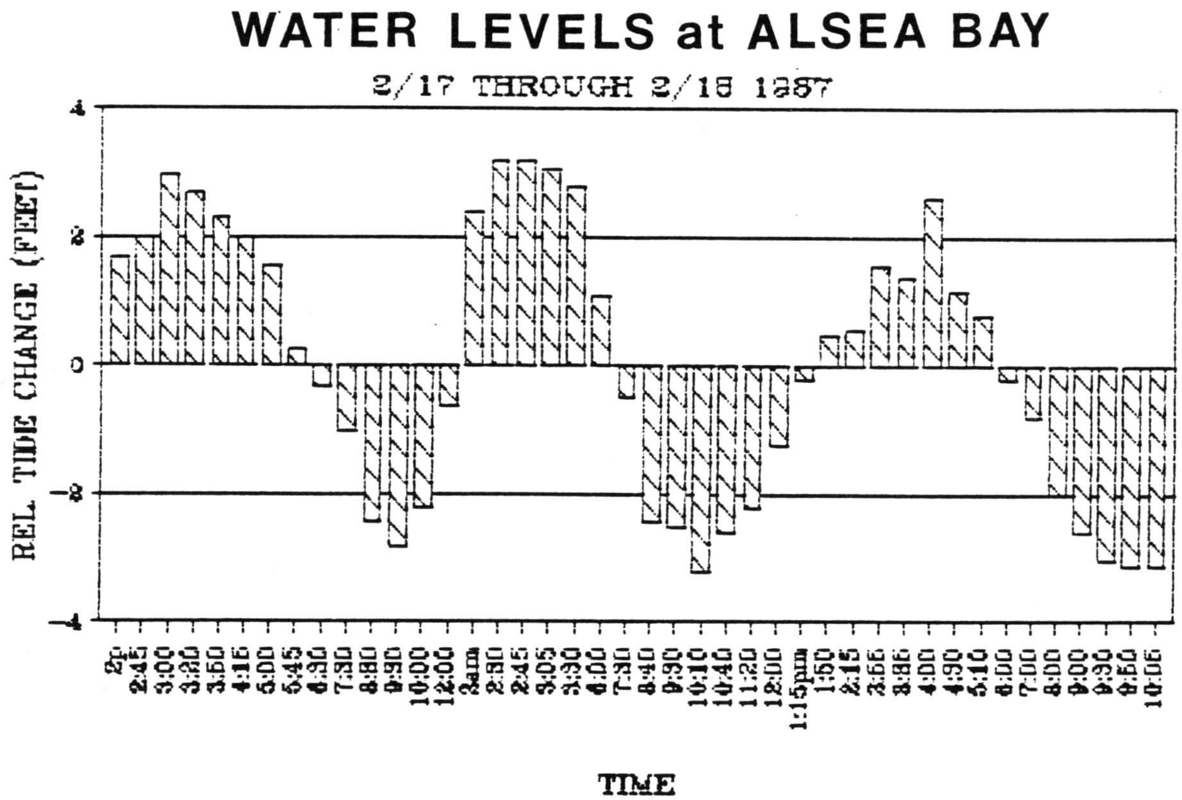


Figure 4. Morphometry of Alsea Bay Inlet, 1987.



Cycle	Expected Range (ft)	Measured Range (ft) (Bay Side)
1	6.8	5.8
2	7.8	6.0
3	6.6	6.4
4	6.0	5.8
5	6.6	5.7
Ave. Range	6.56	5.94

Ave. Constriction .905

Figure 5. Tide Range - 2/17/87 through 2/18/87.

looked in the determination of spit stability. Theoretical models should be replaced with empirical equations when possible, and actual variations in quantities used in lieu of averages. Without the determination of the true range of inputs to a system, the system cannot be accurately assessed. Research on this inlet can be enhanced if the refined cross-sectional area figures, tide prism, and river flow variations are utilized in the future.

It would appear that the concept of "stability" may need redefining in the case of the Alsea inlet, as well as other inlets of similar situation along the Oregon coast. This opinion is put forth by Bruun, advising that a static view of inlet stability is incorrect when studies are focused on inlets influenced by littoral drift (Bruun, 1978).

Much of the research cited in this report compares the results of adjusted stability equations with stability equations using tide prism and littoral transport rates. The effects of littoral transport are not addressed in either this paper, or the research by OSU, since available data on littoral transport rates along the coast of Oregon is minimal at best.

The development of a predictor model, as mentioned above, will be the focus of ongoing research by this author, as well as analysis of the littoral cell that Alsea Bay is a part of. This will allow a better idea of all variables responsible for this erosion event, and others occurring on tidal inlets along the Oregon coast.

CONCLUSION

Using the data sets as determined from U.S.G.S. River Stage Data, U.S. C.G.S. Tide Tables, and field work, stability equations for the Alsea Bay inlet were re-evaluated, and river flow contributions to the tidal prism estimated. It was found that maximum tide range and total tide prism volumes appear to correlate significantly with spit areas. River flow appears to effect the spit configuration only when added to tide prism values. Periods of higher mean flow, when combined with predicted higher tide ranges, result in an erosive loss of spit area. This can be considered the bay system's typical, and possibly predictable, response to changing hydraulic conditions.

Additionally, from reviewing the current literature on inlet dynamics, stability estimates were determined using actual river input and empirically adjusted formulae. The most probable stable cross-sectional area for the inlet was found to range from 1081 m^2 to 1224 m^2. These findings, as well as the research proposed, should enhance the knowledge of this, and other tidal inlets along the west coast.

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Appendix

1. Stability Equation Variations.

2. Maximum Monthly Tide Range.

1. Average Stability without river input.

$$Ac = BP^{n}$$

Ac = Stable cross sectional area   P = Tide prism

B = 1.91×10^{-6} n = 1.1

$$P = \text{Bay area} \times \text{Mean Max. tide range}$$

$$= 9.46 \times 10^{6}\,m^{2} \times 3.00\,m$$

$$= 2.84 \times 10^{7}\,m^{3} = 10.04 \times 10^{8}\,ft^{3}$$

Therefore;

$$Ac = 1.91 \times 10^{-6} \times (10.04 \times 10^{8})^{1.1}$$

$$= 1.91 \times 10^{-6} \times 6.33 \times 10^{9}$$

$$= 12.09 \times 10^{3}\,ft^{2}$$

$$= 1124\,m^{2}$$

Tide prism range is 9.65 to 10.93×10^{8} ft^3

Stable cross sectional area range is 1081m^2 to 1224m^2

2. Maximum Monthly Tide Range Data.

YEAR	AVE. MONTHLY RANGE (FT)	YEAR .	AVE. MONTHLY RANGE (FT)
1959	9.65	1971	9.99
1960	9.69	1972	10.26
1961	9.46	1973	9.84
1962	9.61	1974	9.87
1963	9.60	1975	9.72
1964	9.79	1976	9.99
1965	9.71	1977	9.56
1966	10.00	1978	9.75
1967	10.10	1982	10.05
1968	10.20	1983	9.76
1969	9.95	1984	9.96
1970	10.03	1985	10.74

MEAN = 3.00 M   RANGE IS 2.88 TO 3.27 M

Source: US CGS Tide Tables