University of Washington
Department of Civil and Environmental Engineering

BIRCH BAY MARINA: HYDRAULICS OF PROPOSED EXPANSION

Eugene P. Richey
Norman H. Smith

Water Resources Series
Technical Report No. 53
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Prepared for
Colman and Riddell, Inc.
Seattle, Washington

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INTRODUCTION

The hydraulic characteristics of the Birch Bay Marina in the proposed expanded configuration were assessed for three tidal ranges, a low (3.0 feet), the average (5.9 feet), and a high value (10.0 feet). These results were then compared to those from the study for the Marina in its present dimensions, and then with those from studies of a similar nature that have been carried out on other marinas on Puget Sound. One of the best standards against which to judge the impact of the proposed expansion is to compare it with the existing marina. Therefore, considerable attention is given to describing the existing marina.

The objective of the study on the marina in its present form was to relate hydraulic characteristics with a related study of water quality, fish and shellfish conducted by Washington State Fisheries. The objective of the study on the expanded from was to assess the impact of the expansion. Thus, the subject matter of the two studies were very closely related, but they were carried out for different purposes, and have been written as separate reports. However, to avoid needing both reports on hand to consider the effects of the expansion, much of the basic information appearing in the first report (Richey and Haury) is repeated herein.

The characteristics are described in terms of three major, interdependent components, a tidal prism ratio, an exchange (flushing coefficient), and circulation patterns. The tidal prism ratio is the ratio of the water volume between low and high tide to the total basin volume, and is a measure of the potential exchange of basin water with each tide; it can be computed from geometric data alone. The exchange coefficient is the tidal-averaged water exchange on each tide, and is determined experimentally in the hydraulic model. In previous studies (see References) this quantity was obtained only by a fluorescent dye technique. Similar procedures were followed in the present study, but a photodensiometric technique which provides considerable detail has been used also. A third characteristic relates to circulation and mixing within the basin. These patterns were identified and evaluated qualitatively from observation of the fate of a tracer dye in the model and records obtained by both sequential still (35 mm) photographs and time-lapse cine photography. (A set of 35 mm slides and copy of the cine films are transmitted with the base copy of the report and are considered a part of that report).

LOCALE

Birch Bay was named by Captain Vancouver in June 1792 (Meany, 1957) in recognition of the abundance of black birch in the area. He gave its location as Latitude 48° 53 1/2', Longitude 237° 33'. Its position in relation to the region is shown on Figure 1, and the marina location in the Bay on Figure 11. (Figures 2-10 are reproductions from the 35 mm slides). Tides typical of the period August-October 1977 are shown on Figures 12 and 13.

THE MODEL

Typically, estuaries and bays are much wider than they are deep, so that models of them usually are built on distorted scales. The laboratory basin used for the study had a working area of 8 feet by 12 feet and a depth of 18 inches. A scale distortion of 1:10 has been used on most of the studies on the reference marinas. The Froude Law modelling criteria, the available basin size, and the conventional distortion ratio led to the following set of scale ratios:

Length, horizontal	X_r	1:360
Length, vertical	Z_r	1:36

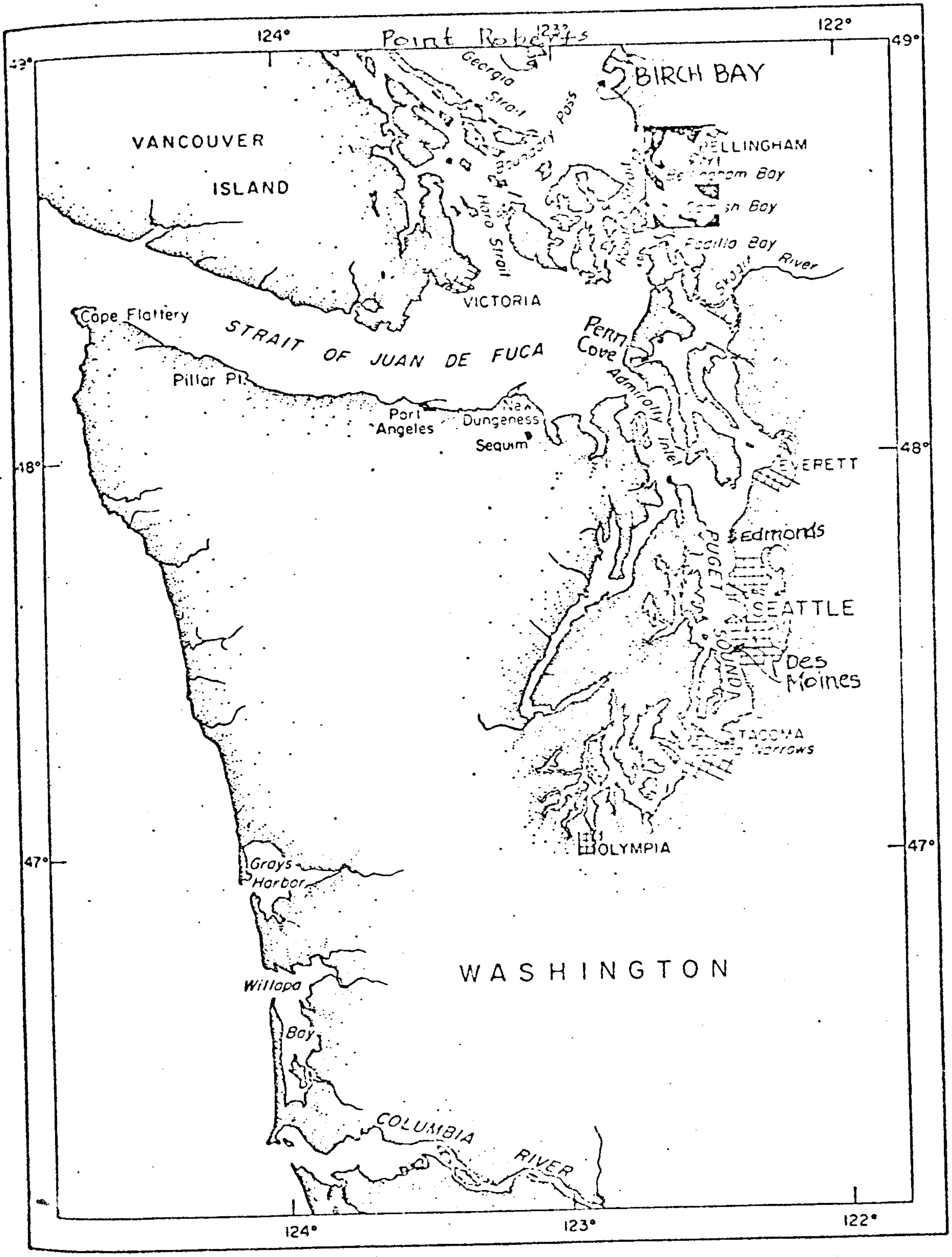


Figure 1. Location of Birch Bay

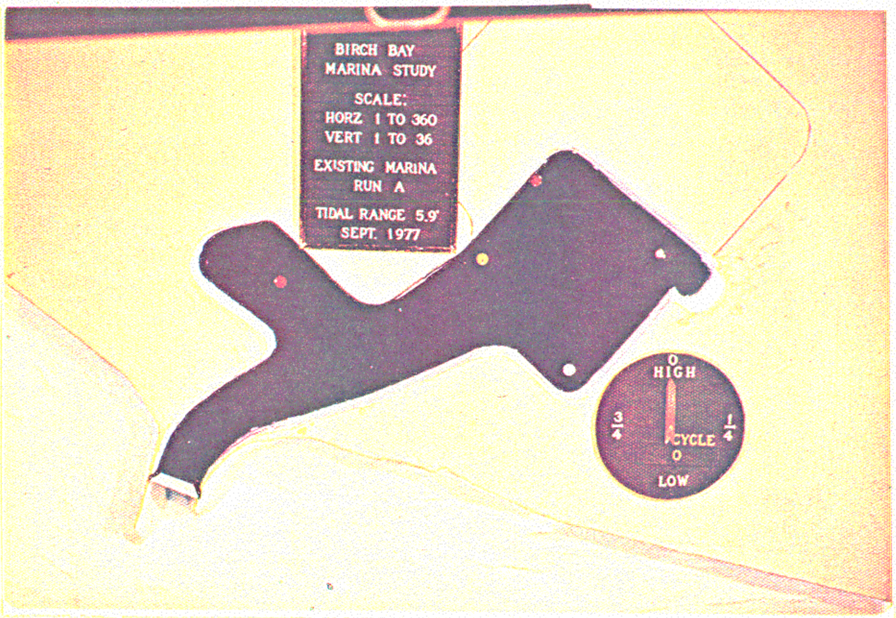


Figure 2a. Birch Bay Marina 0/0

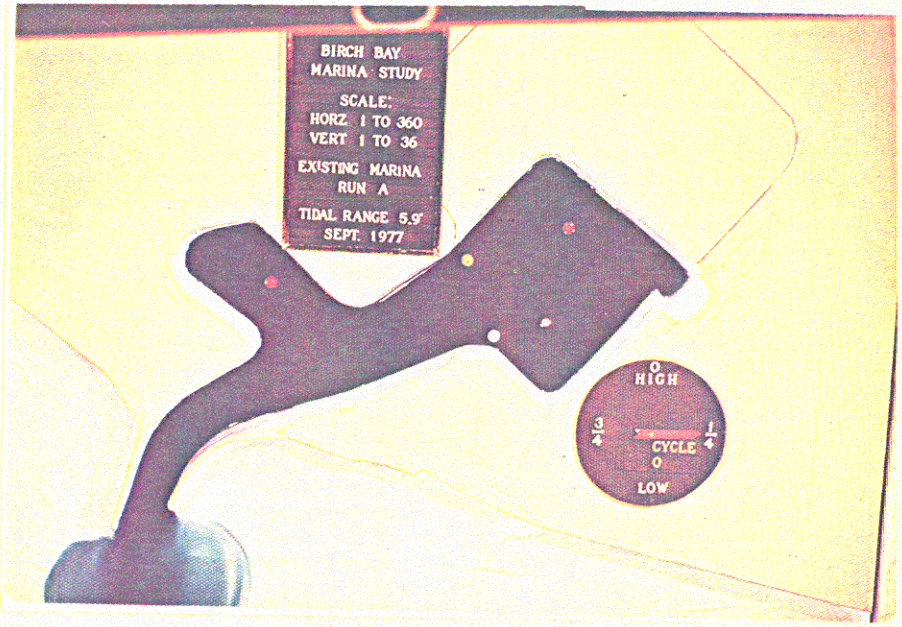


Figure 2b. Birch Bay Marina 0/1

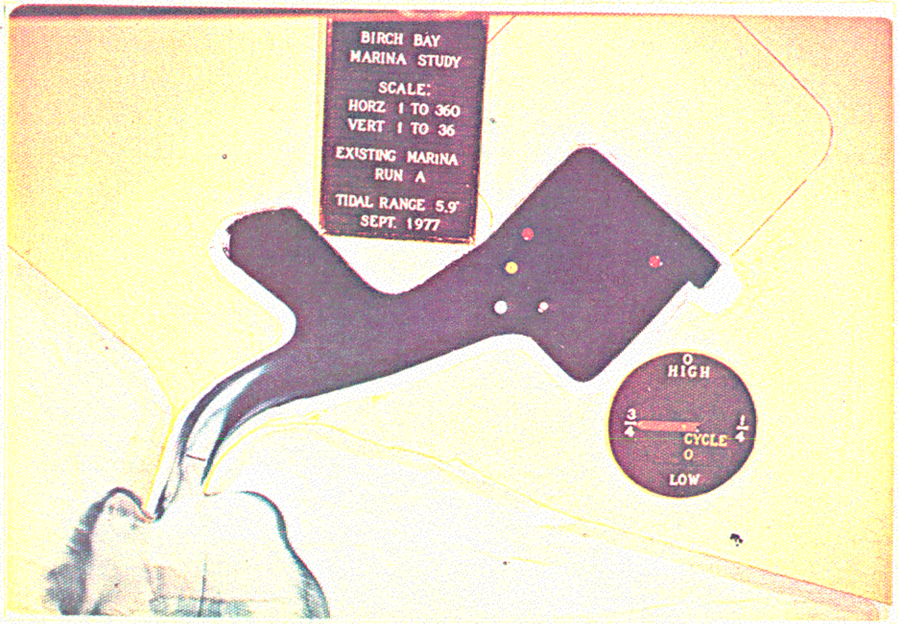


Figure 2d Birch Bay Marina 0/3

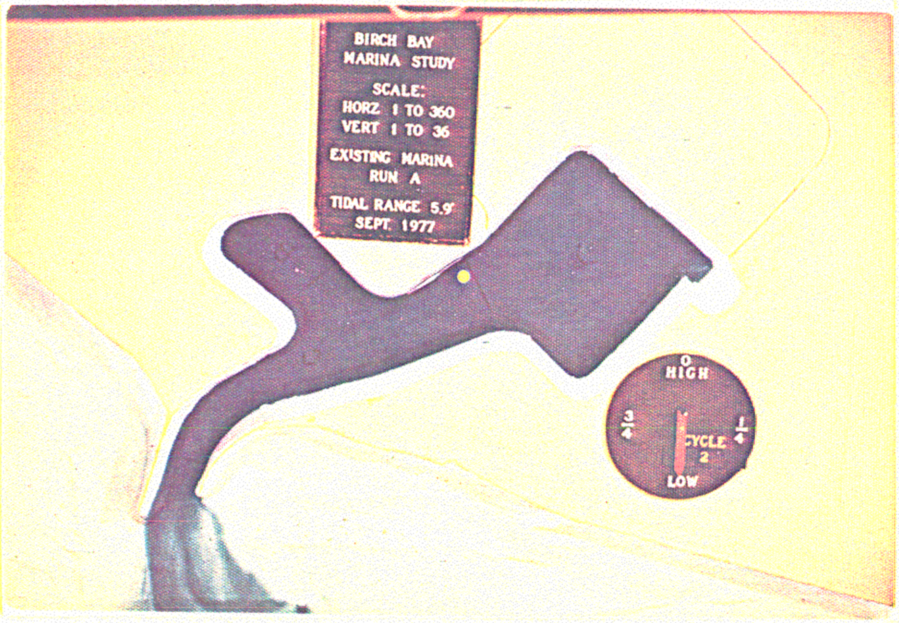
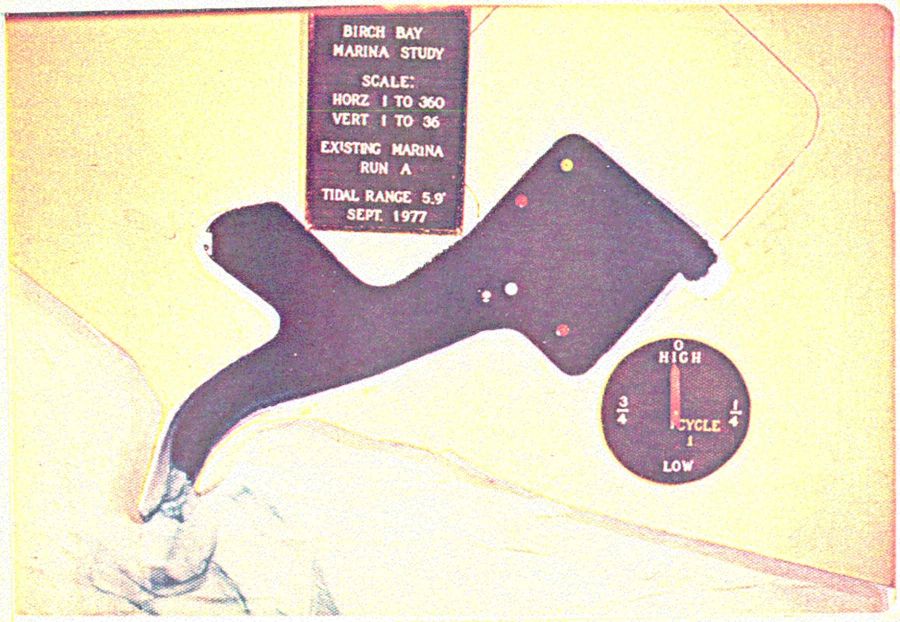


Figure 2c. Birch Bay Marina 0/2



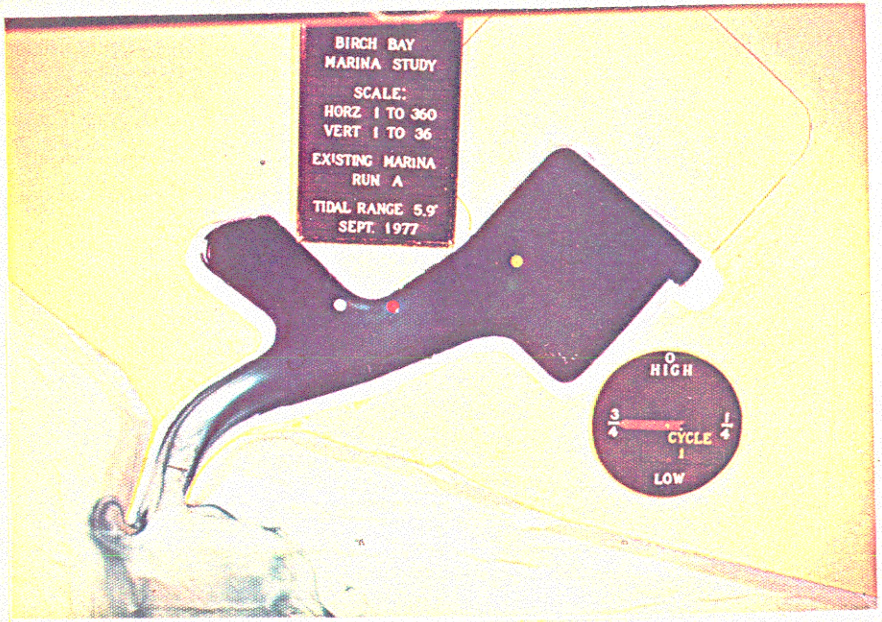


Figure 3a. Birch Bay Marina 1/0

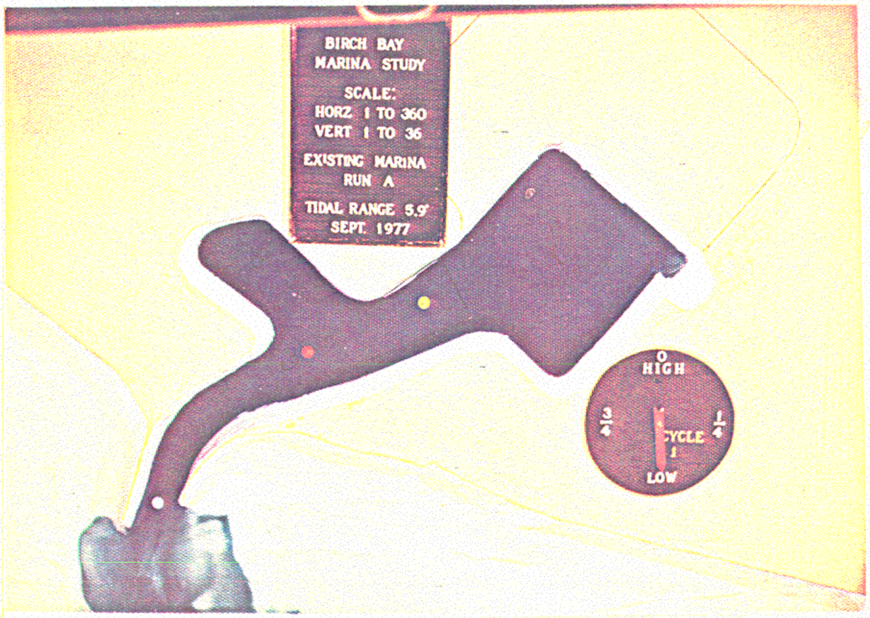


Figure 3b. Birch Bay Marina 1/1

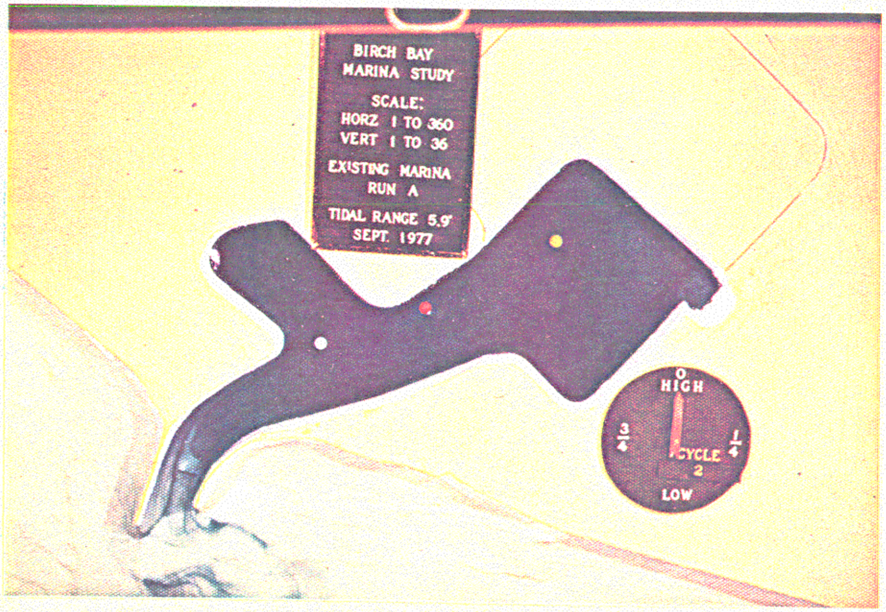


Figure 4d. Birch Bay Marina 2/0

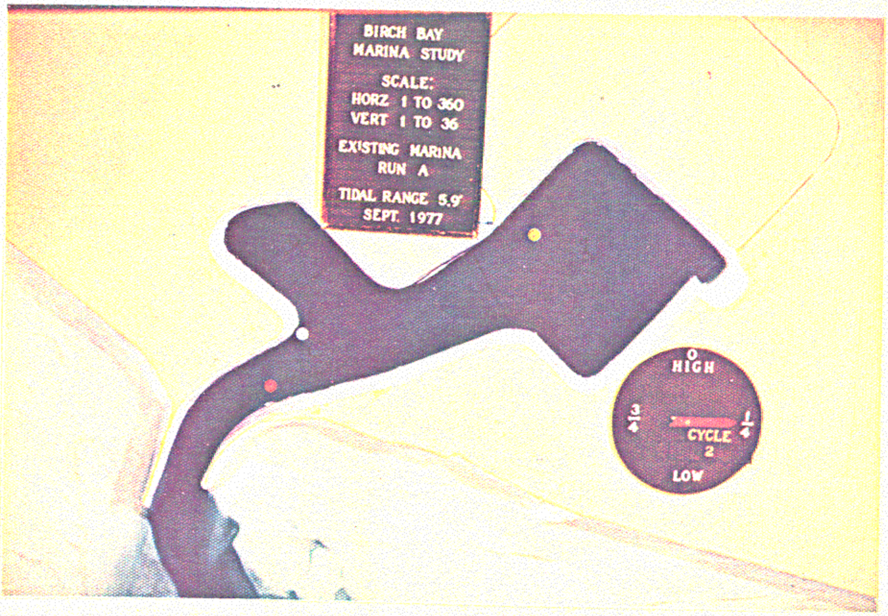


Figure 4b. Birch Bay Marina 2/1

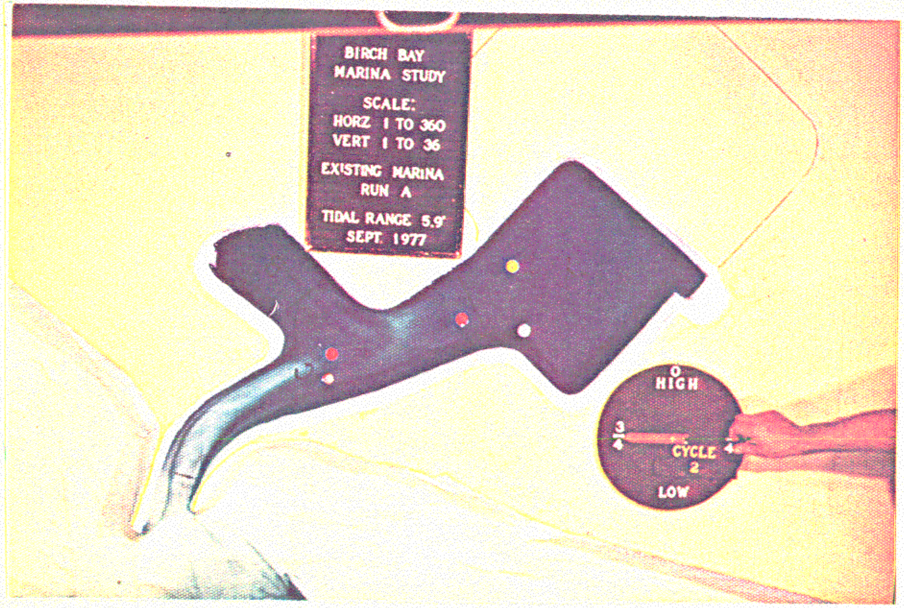


Figure 4d. Birch Bay Marina 2/3

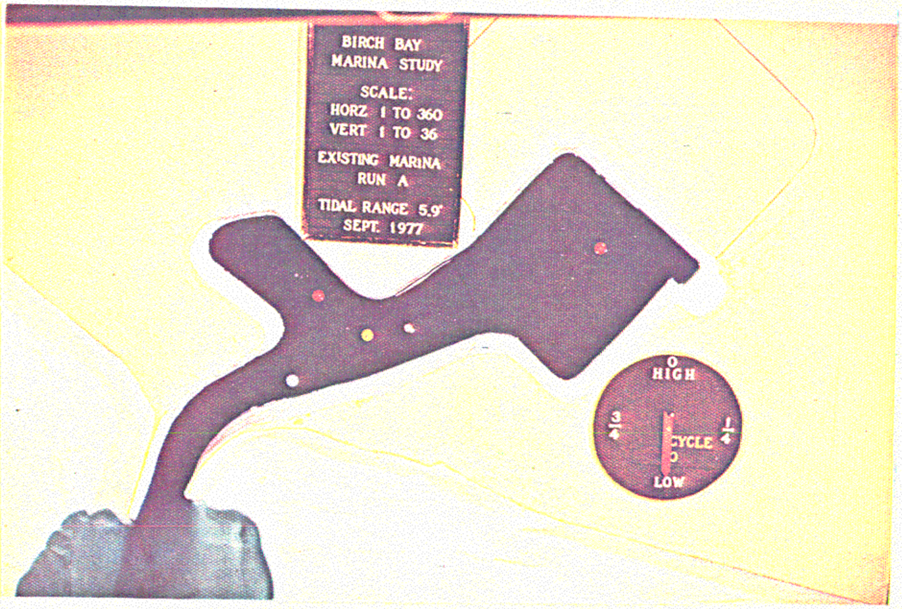


Figure 4c. Birch Bay Marina 2/2

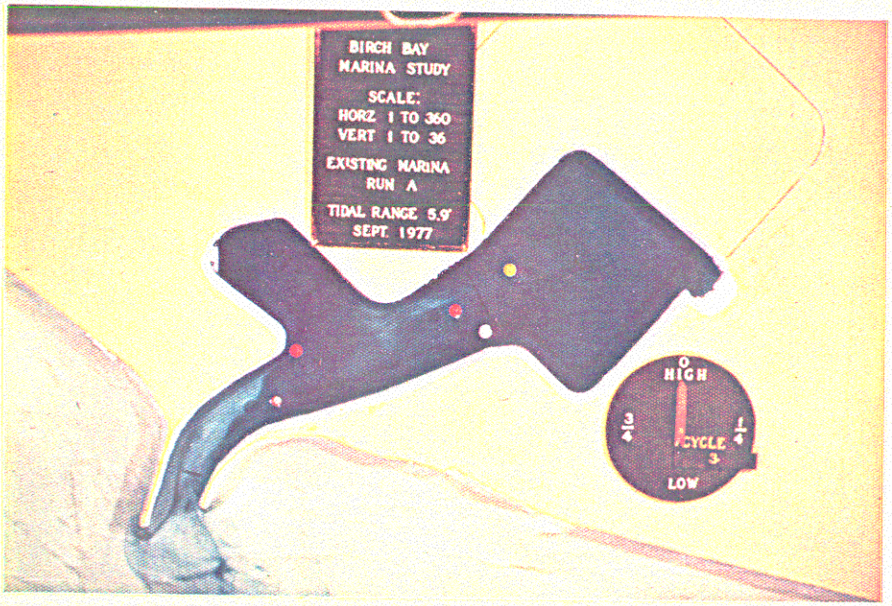


Figure 5a. Birch Bay Marina 3/0

Figure 5b. Birch Bay Marina 3/1

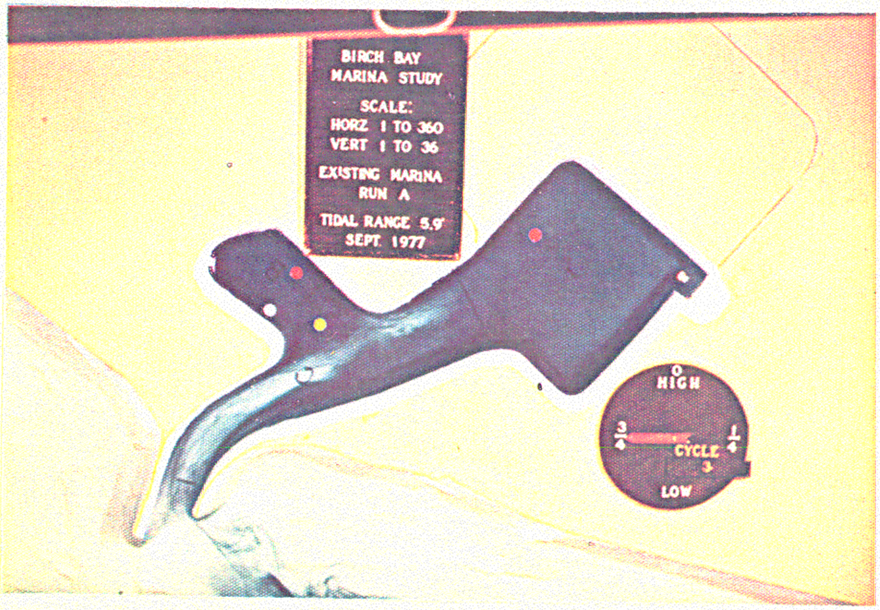


Figure 5d. Birch Bay Marina 3/3

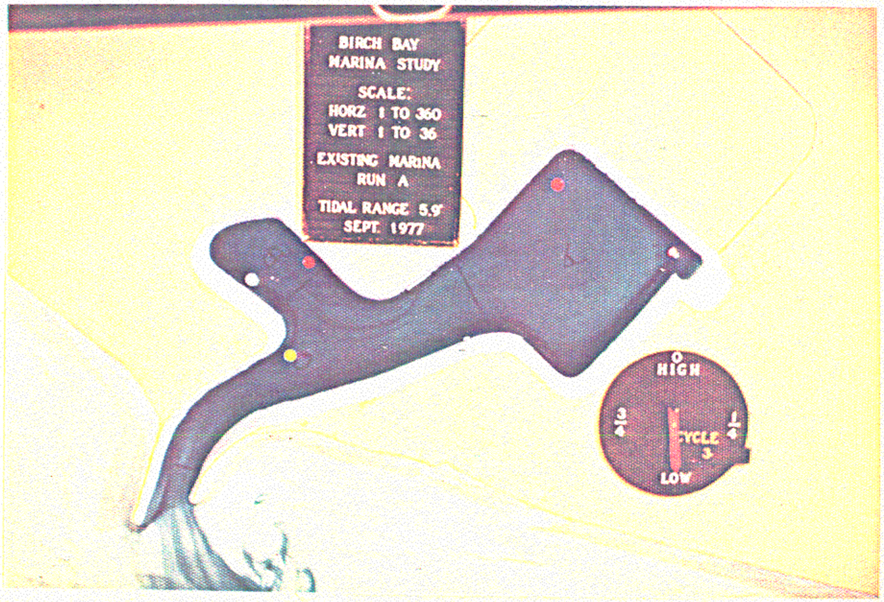


Figure 5c. Birch Bay Marina 3/2

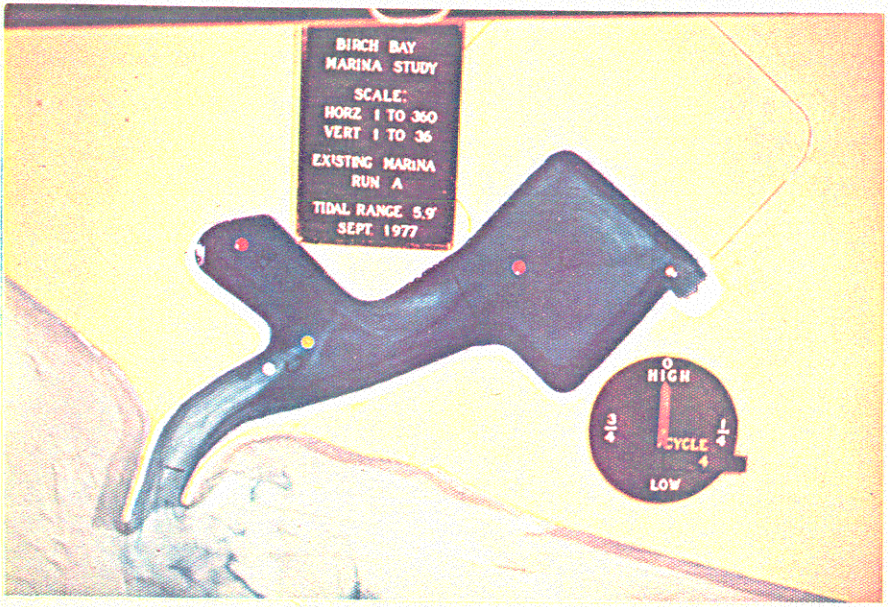


Figure 6a. Birch Bay Marina 4/0

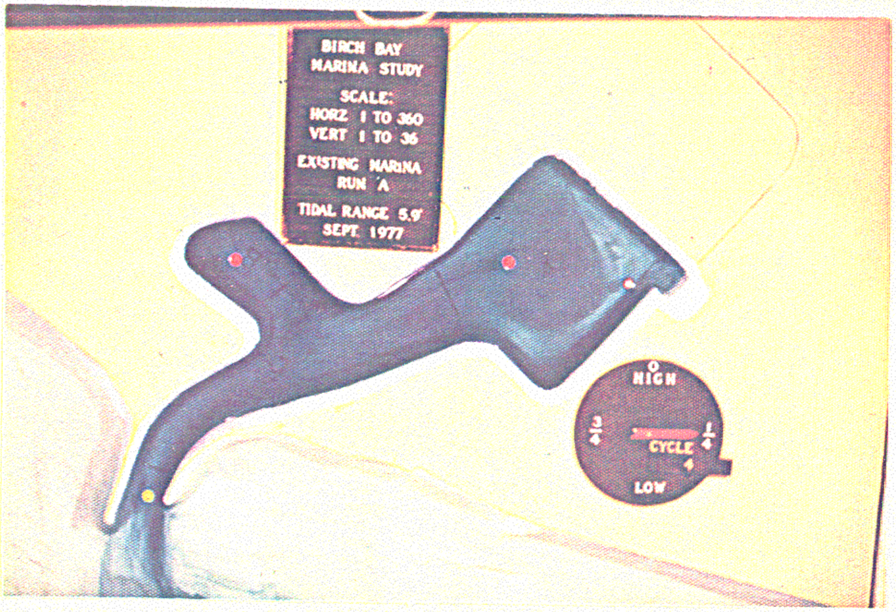


Figure 6b. Birch Bay Marina 4/1

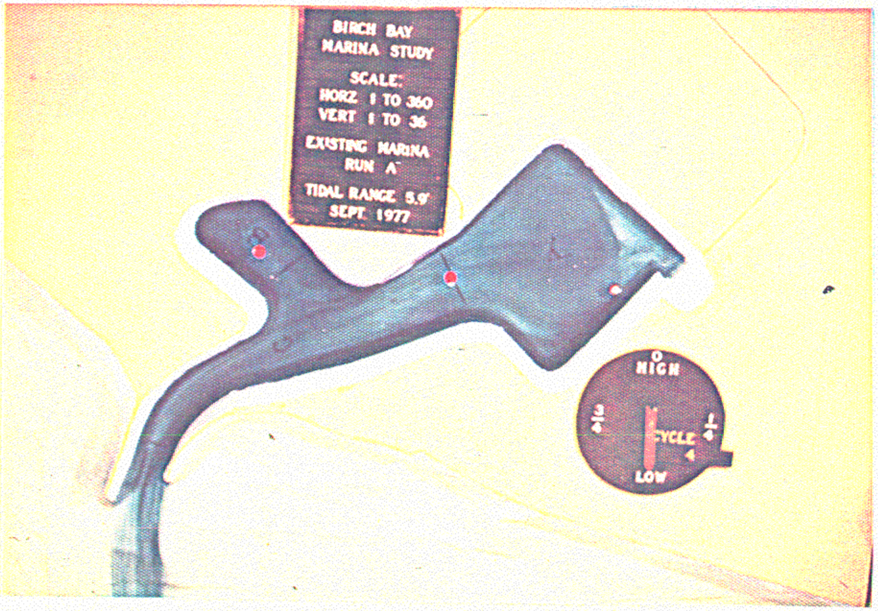


Figure 6c. Birch Bay Marina 4/2

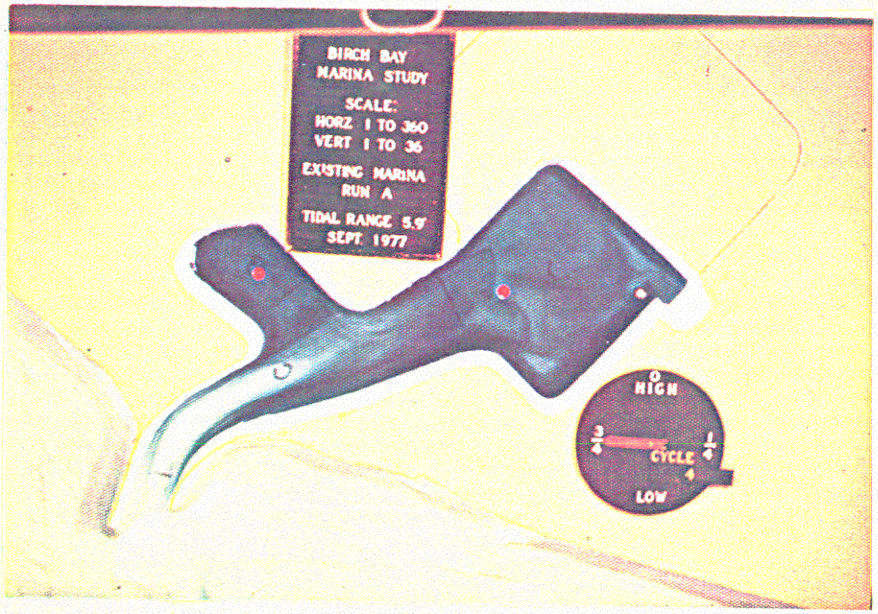


Figure 6d. Birch Bay Marina 4/3

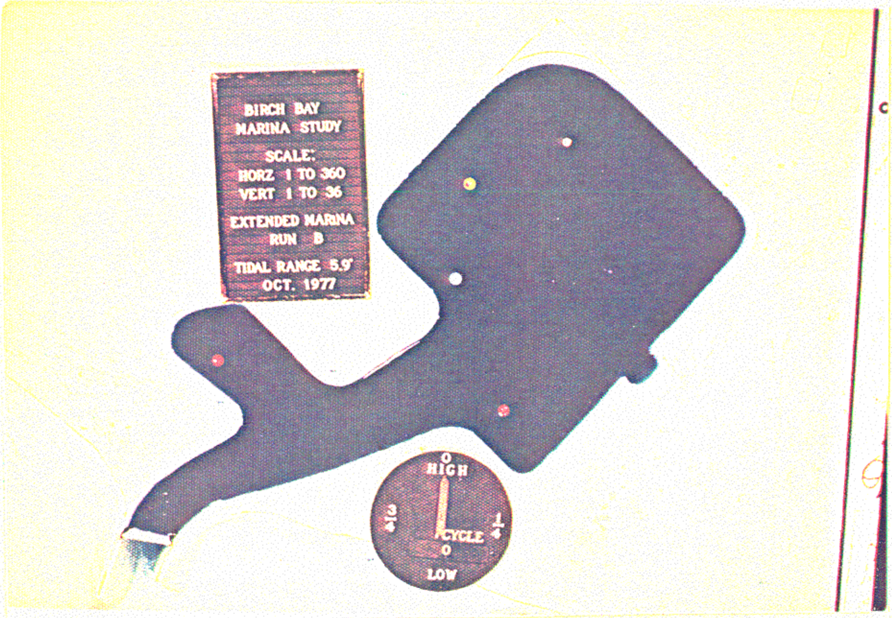


Figure 7a. Birch Bay Marina 0/0 Extension

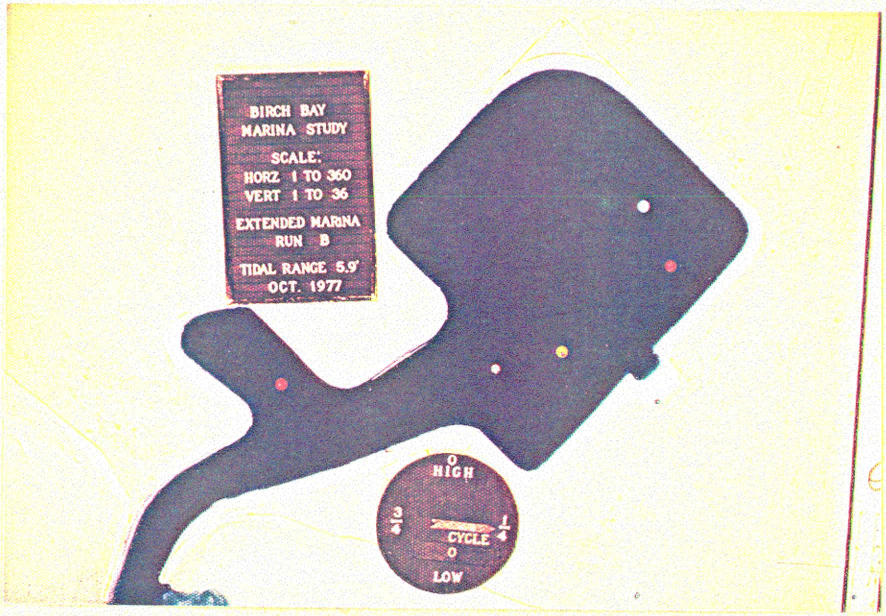


Figure 7b. Birch Bay Marina 0/1 Extension

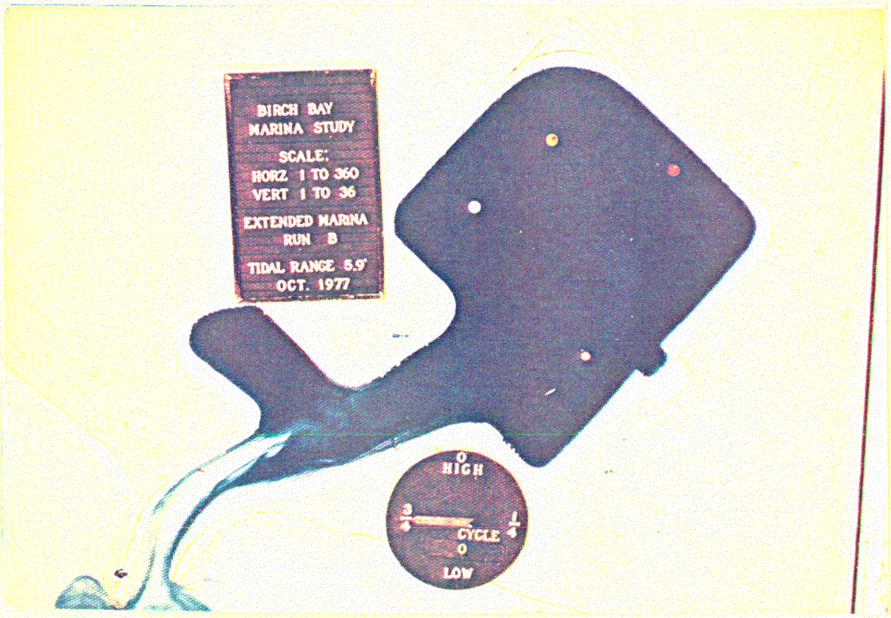


Figure 7d. Birch Bay Marina 0/3 Extension

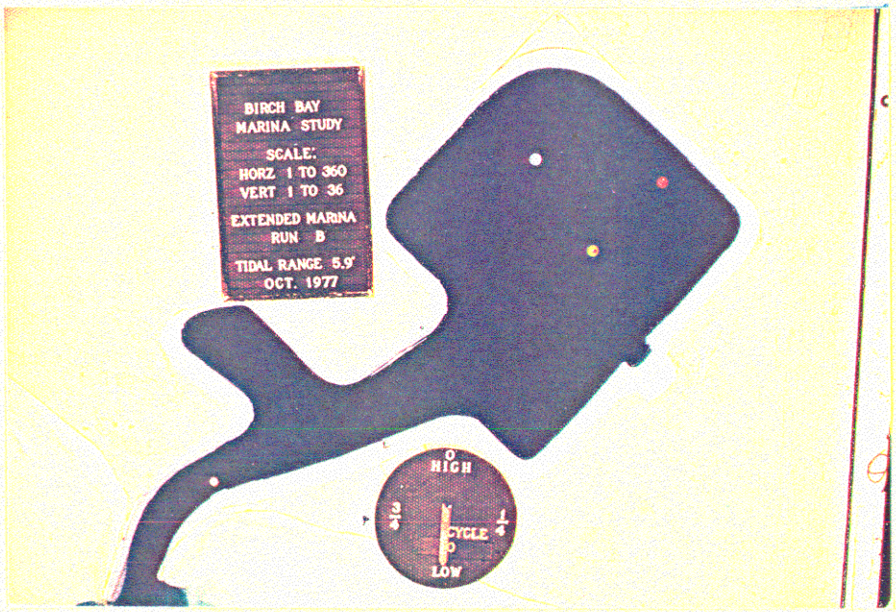


Figure 7c. Birch Bay Marina 0/2 Extension

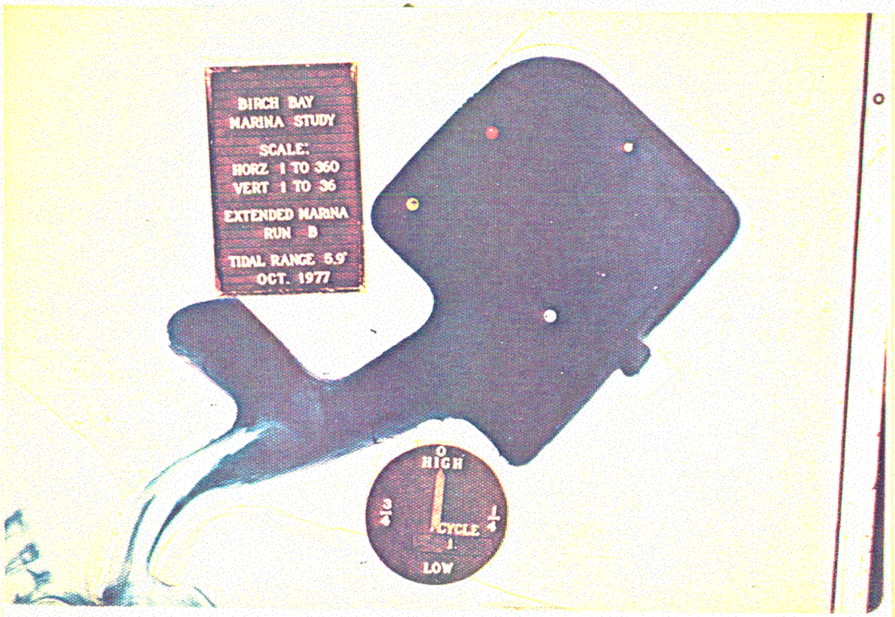


Figure 8a. Birch Bay Marina 1/0 Extension

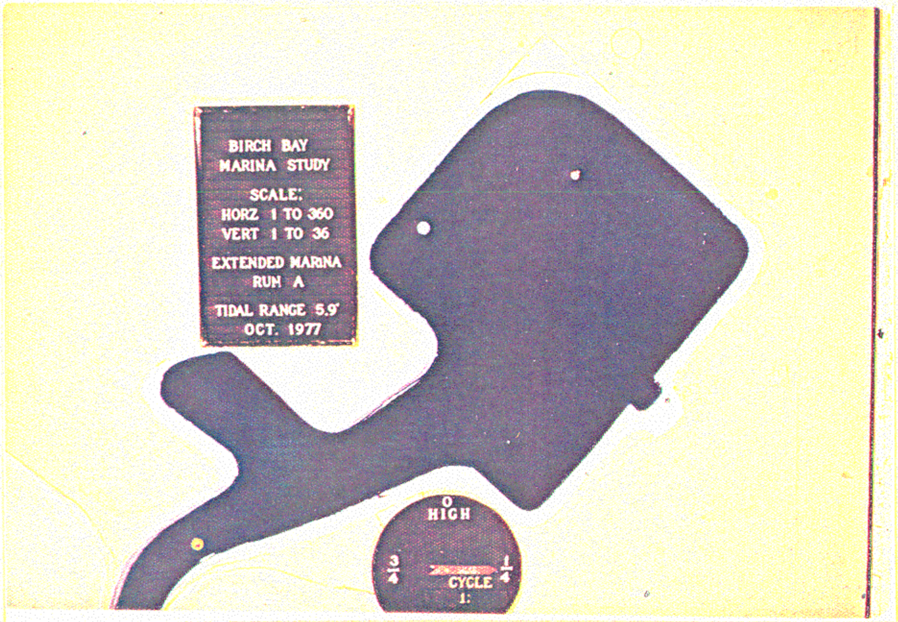


Figure 8b. Birch Bay Marina 1/1 Extension

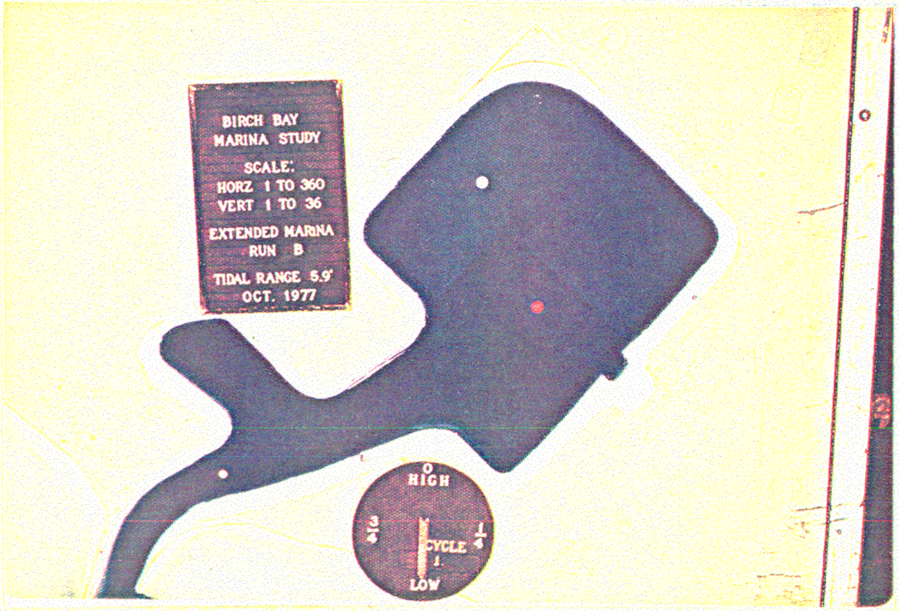


Figure 8c. Birch Bay Marina 1/2

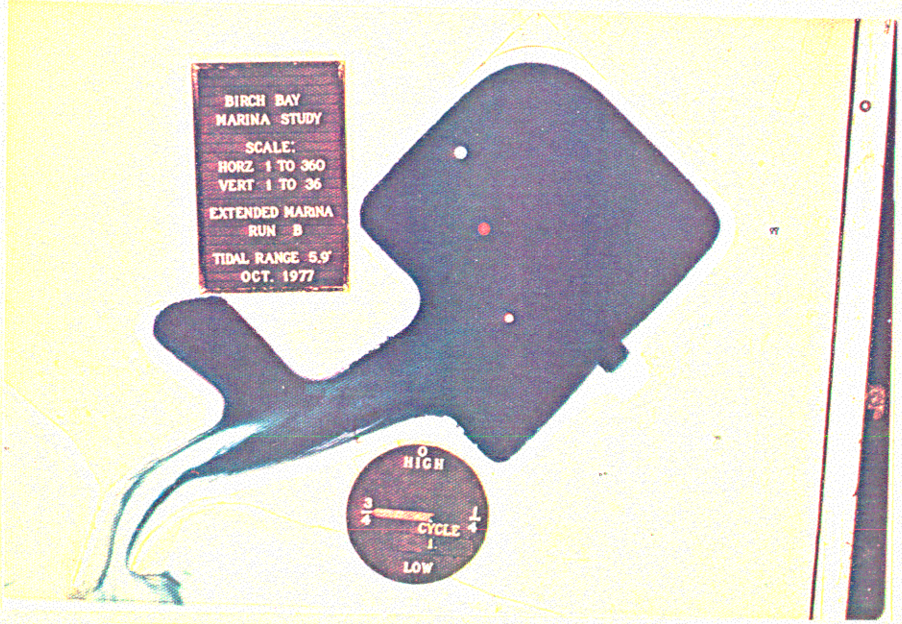


Figure 8d. Birch Bay Marina 1/3 Extension

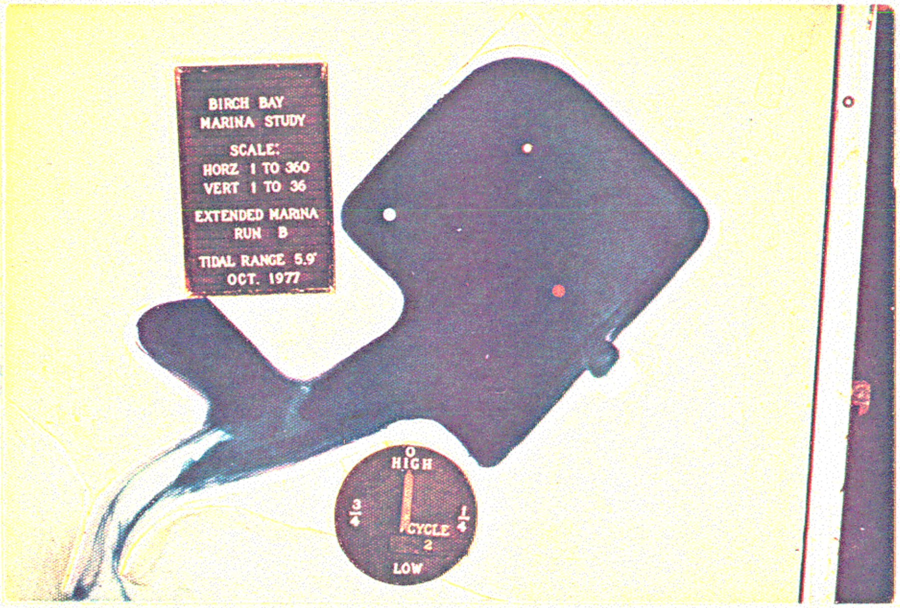


Figure 9a. Birch Bay Marina 2/0 Extension

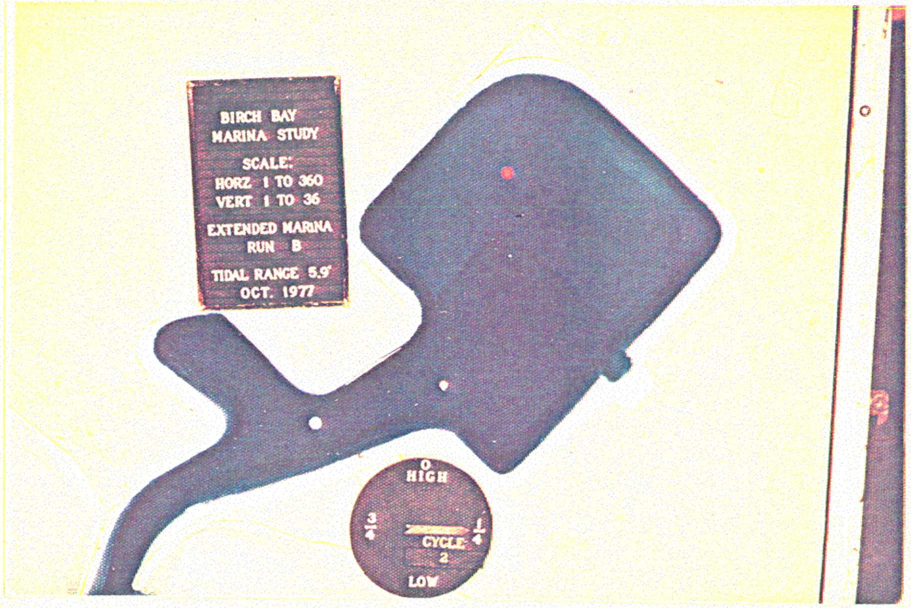


Figure 9b. Birch Bay Marina 2/1 Extension

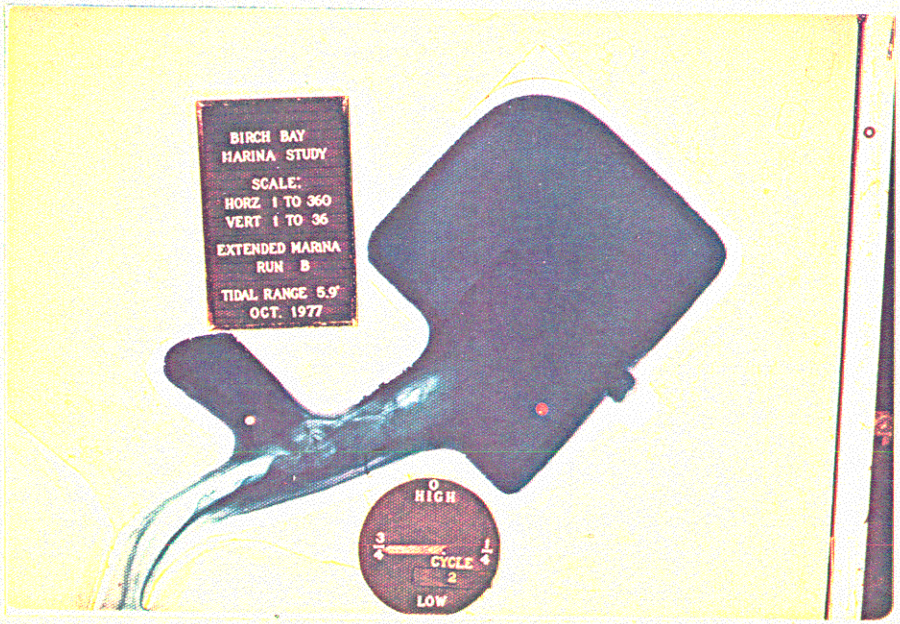


Figure 9d. Birch Bay Marina 2/3 Extension

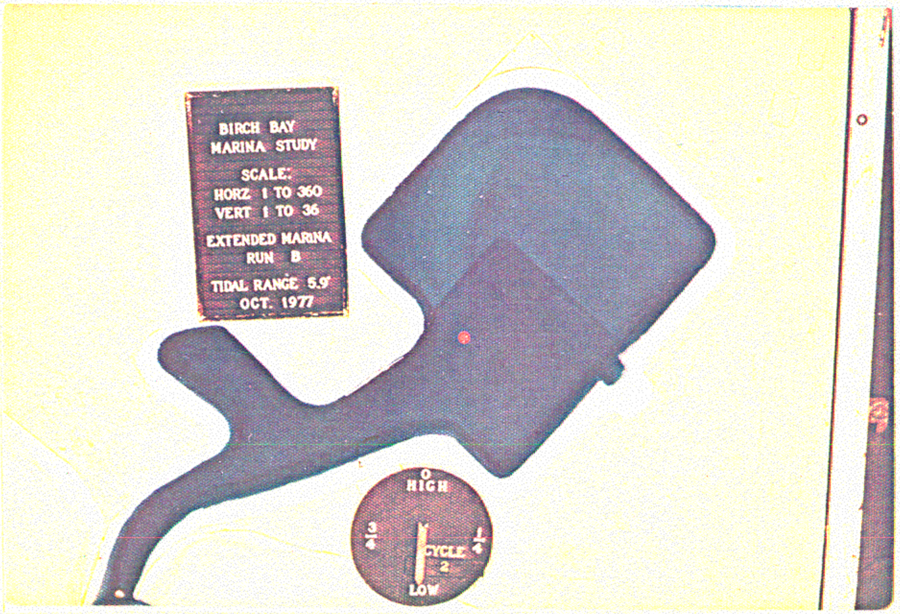


Figure 9c. Birch Bay Marina 2/2 Extension

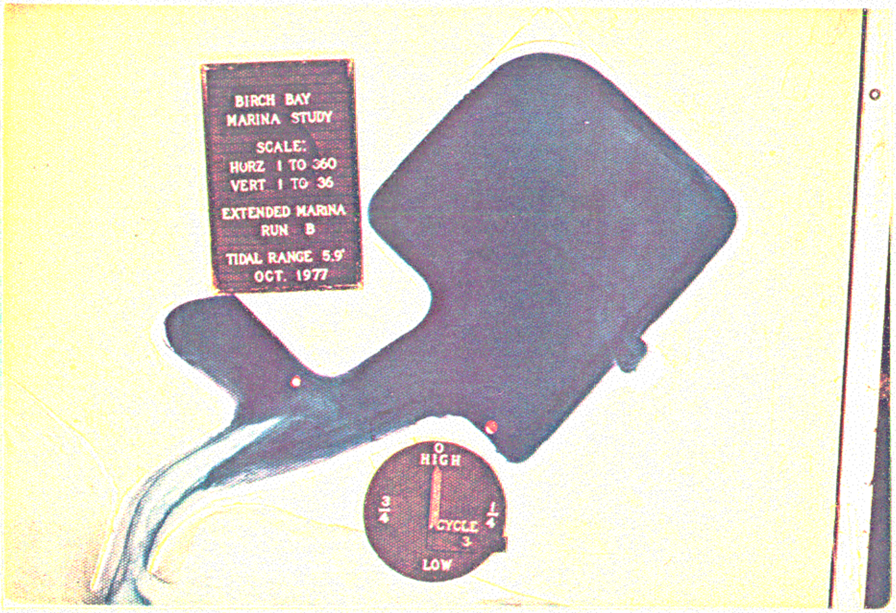


Figure 10a. Birch Bay Marina 3/0 Extension

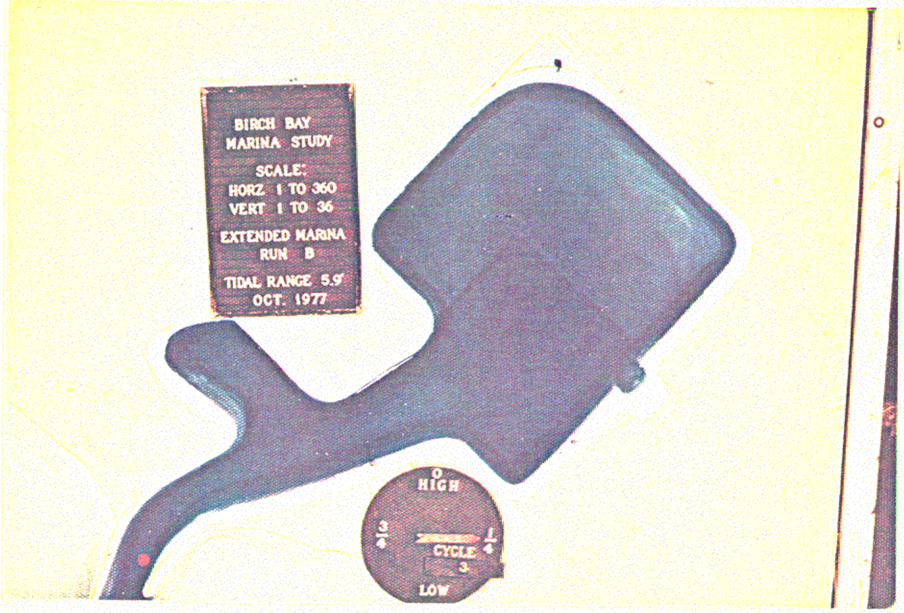


Figure 10b. Birch Bay Marina 3/1 Extension

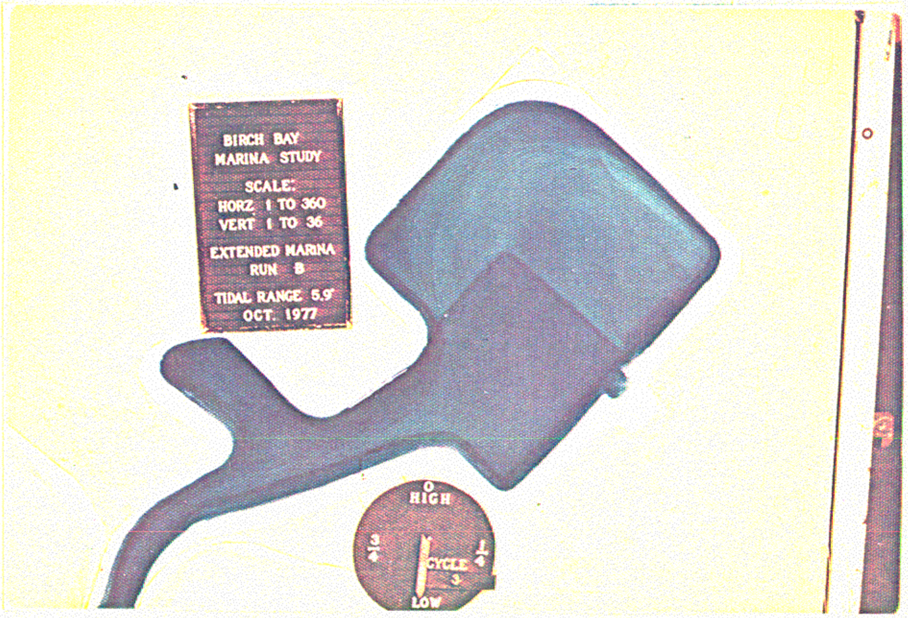


Figure 10c. Birch Bay Marina 3/2 Extension

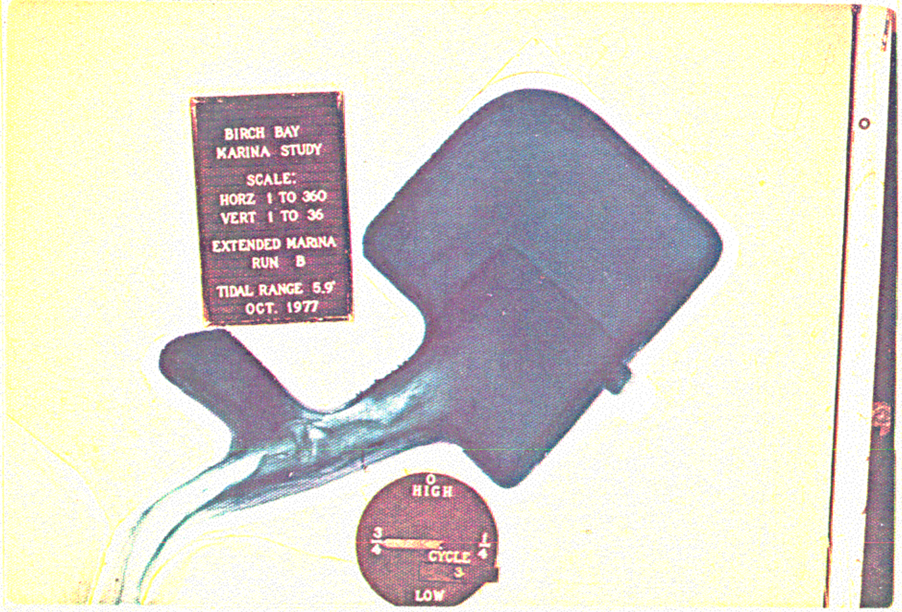


Figure 10d. Birch Bay Marina 3/3 Extension

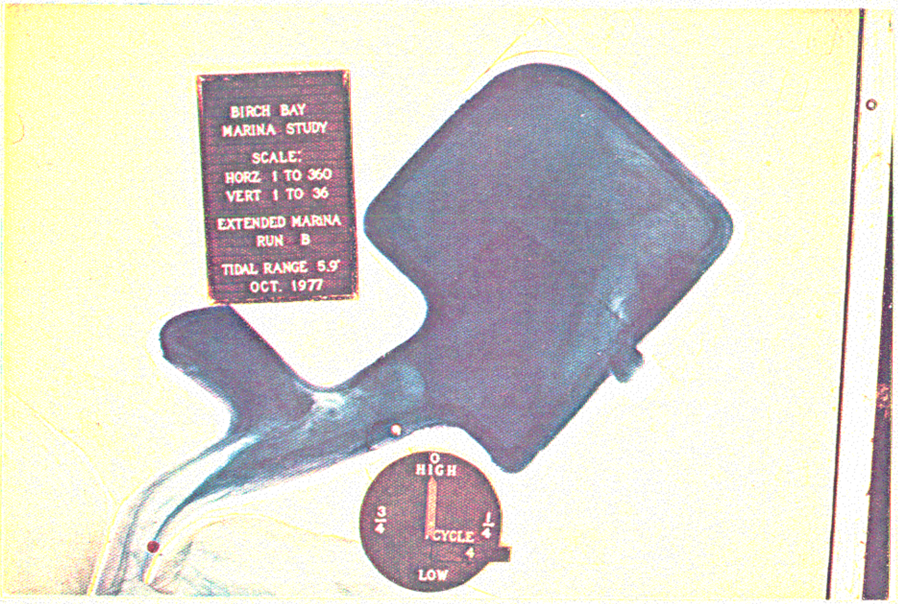


Figure 11a. Birch Bay Marina 4/0 Extension

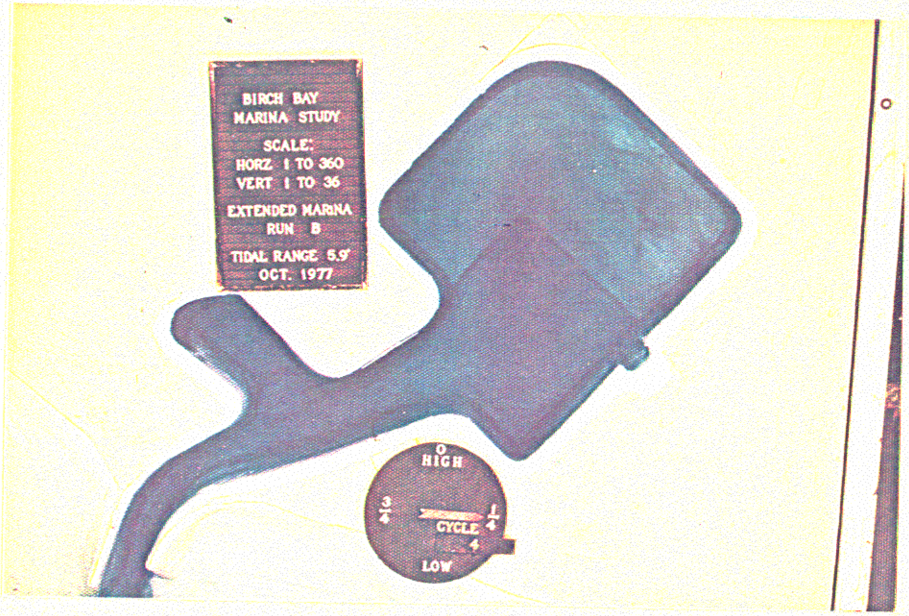


Figure 11b. Birch Bay Marina 4/1 Extension

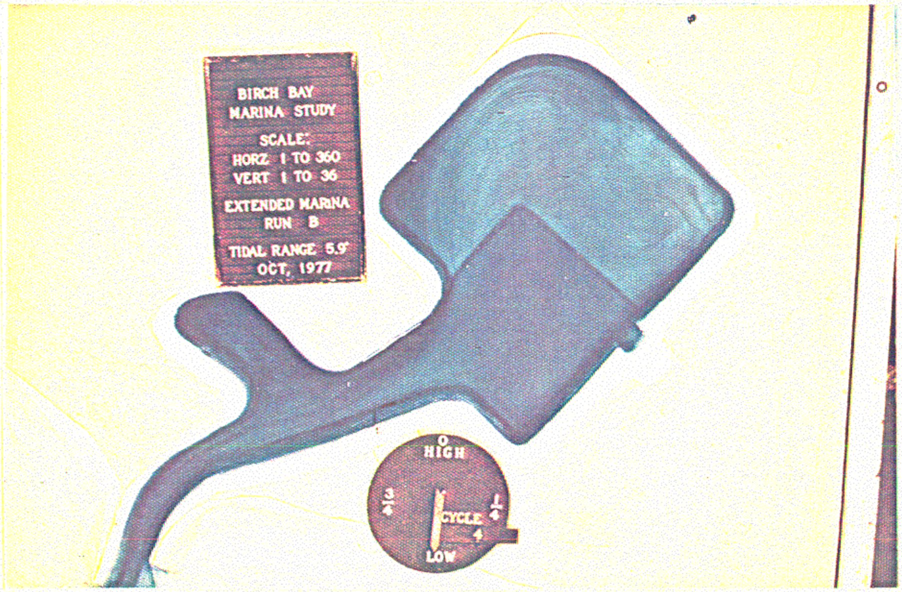


Figure 11c. Birch Bay Marina 4/2 Extension

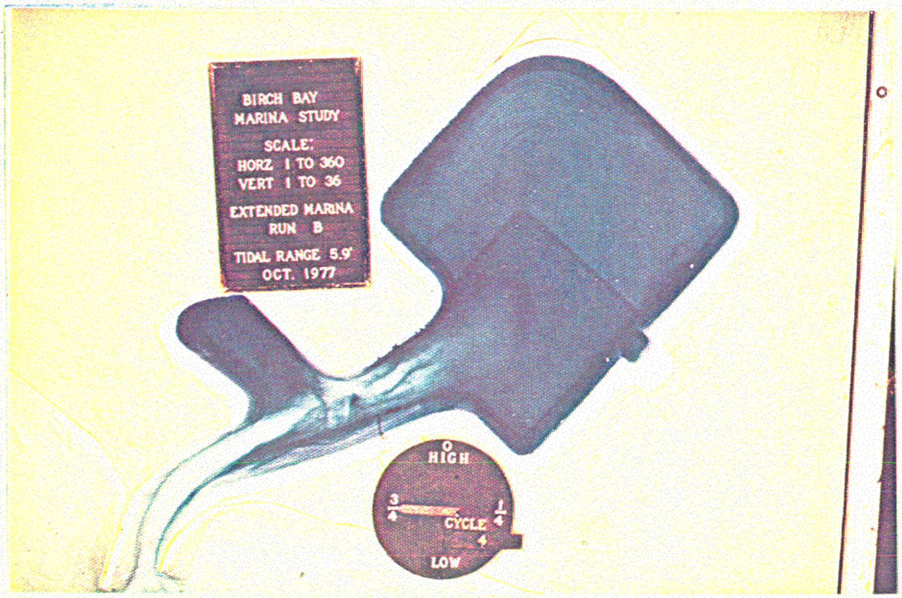


Figure 11d. Birch Bay Marina 4/3 Extension

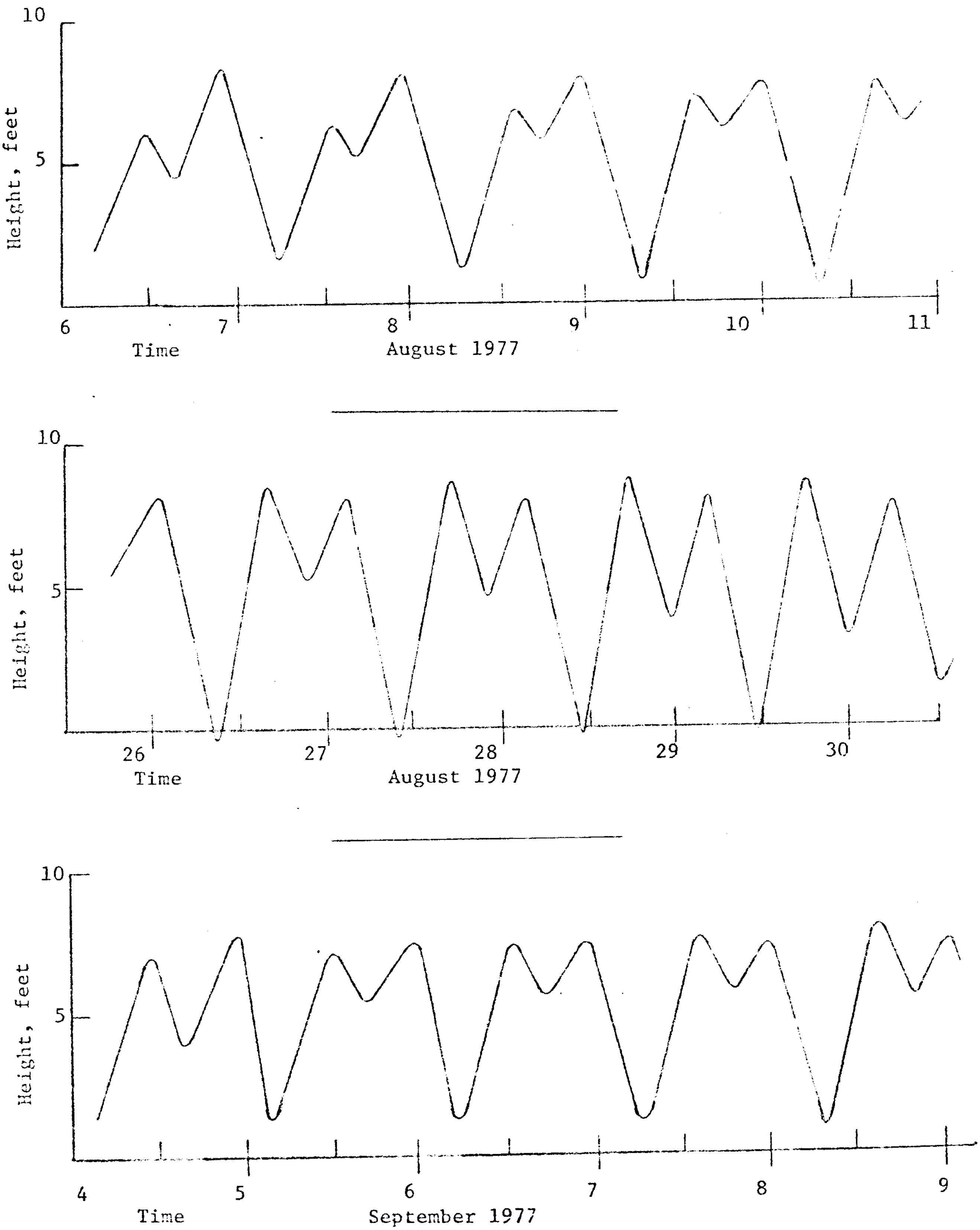


Figure 12. Tides in Birch Bay

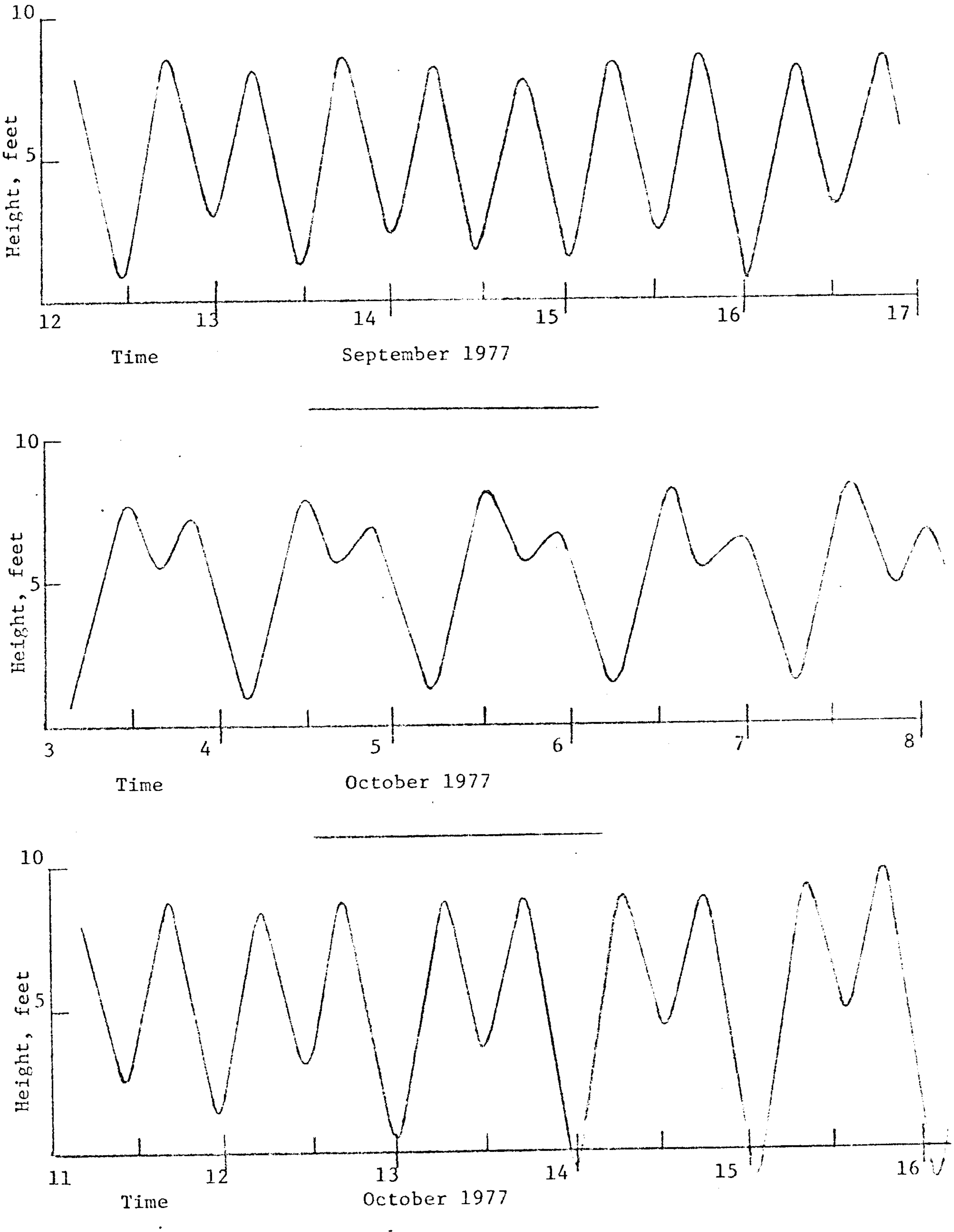


Figure 13. Tides in Birch Bay

Velocity	$Z_r^{1/2}$	1:6
Time	X_r/L_r	1:60
Tidal cycle, prototype	12.4 hours	12.4 minutes model

The single-density, distorted model successfully represents major tidal circulation effects, but does not correctly duplicate features like point-source pollutants, water density stratification, and wind stress on the movement and mixing of local waters. Boats and boat slips are not modelled, but are believed to influence only surface layers and not the main tidal action. The mixing by boat motors is not considered.

The existing marina and the proposed extension are shown on Figure 14; the model was built first to the extreme boundaries of the proposed extension, including the proposed dredged depths, then reduced to the "existing" marina by inserting shaped plugs to block out the extension and to bring up the bottom elevations into agreement with on-site measurements by Cardwell. There is a sill now at the entrance to the marina. The testing was done first on the existing configuration, then the bottom fillers and plugs were removed to bring the model into geometric agreement with the proposed expanded form.

The tide generator for the model basin can produce only sinusoidal tides, with an amplitude fixed for any one series. Statistical data for the tides at Birch Bay are given in Table 1, with data for the highest 20- and the lowest 20 consecutive tides in period August-October 1977. Sets of these tides have been given on Figures 12 and 13 to show the mixed-tide typical of the region. The model could duplicate quite closely the near-sinusoidal tides like those of September 13-15, but could not adapt to the mixed tides of the other periods. However, it has been shown that exchange results for an average tide are very close to those obtained by

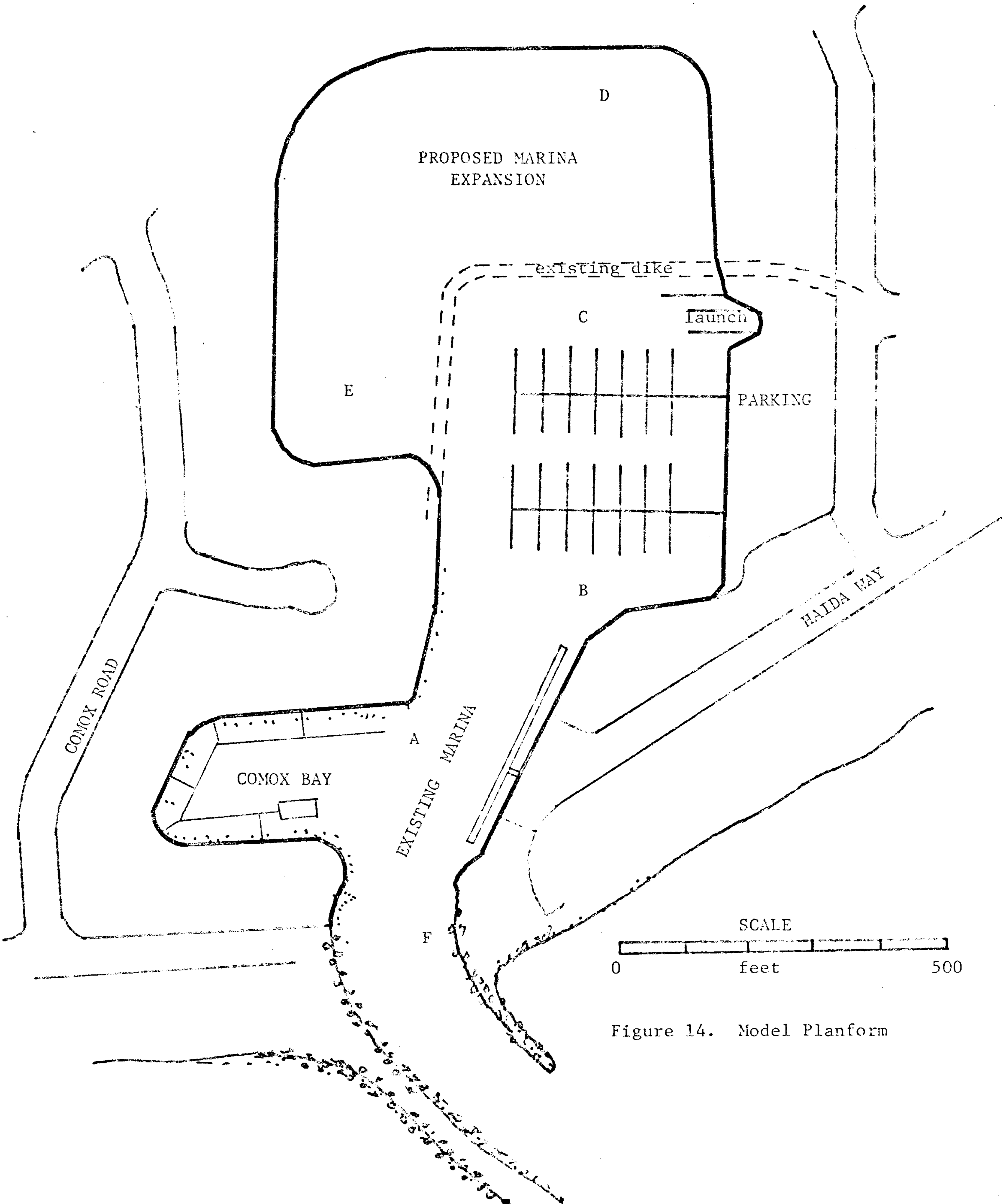


Figure 14. Model Planform

Table 1. Tidal Statistics for Birch Bay
(taken at Semiahmoo Bay, Blaine, Washington)
USCGS Tide Tables
Datum MLLW

Mean Range	5.9 feet	Normal Max Tide Range	13.0 feet
Diurnal Range	9.5 feet	Normal High Spring	9.5 feet
Mean Tide Level	5.6 feet	Extreme Heights	+11.5 and
		(Bellingham Bay)	-4.5 feet

Selected Data 1977

Highest 20 Consecutive Tides	August 25-30	September 12-17	October 11-16
Average High, feet	8.6	8.3	8.9
Average Low	2.1	1.8	1.8
Average Range	6.5	6.5	7.1
Lowest 20 Consecutive Tides	6-11	4-9	3-10
Average High, feet	7.6	7.4	7.5
Average Low	3.3	3.1	3.2
Average Range	4.4	4.3	4.3

algebraically averaging results from the series of tides with unequal amplitudes which compose the average series.

The average tidal height in Birch Bay is 5.6 feet and average range is 5.9 feet. This height and range were used in the model for basin comparison runs and the photographic records. A series was run for both the low amplitude range (3.0 feet) and high range (10.0 feet).

TESTING PROCEDURES

Exchange Coefficient by Dye Technique

Rhodamine-WT, a dye whose fluorescent properties can be used as an index of relative concentration, was prepared for lab use by diluting a 20% solution by 1:1000. Water was circulated through the basin for several minutes ahead of final filling to minimize temperature-induced density gradients. A temporary dam was placed at the entrance to the marina, and an amount of dye (about 30 milliliters) adjusted to the tidal range and fluorometer scale was added and mixed thoroughly. Samples were withdrawn to determine the initial concentration, C_o. Special care was taken to eliminate the effects on dye fluorescence of sunlight, temperature, and chlorine. Dye concentrations were measured with a Turner 110 Fluorometer. The tide generator was started and simultaneously, the dam was removed; after four complete cycles, the generator was stopped, and the basin again isolated, thoroughly mixed, and samples were withdrawn and final concentration C_i was measured.

For a series of equal tides, the average per cycle exchange coefficient was determined from the equations

$$E = 1 - R \quad \text{and}$$

and

$$R = (C_i/C_o)^{1/i}$$

where E = average, per cycle exchange coefficient

R = average, per cycle retention coefficient

C_o = initial spatial average concentration

C_i = spatial average concentration after i cycles (usually $i = 4$).

Exchange coefficients for three tide ranges, 3.0, 5.9, and 10.0 feet were obtained following the above procedures.

Exchange Coefficient by Photodensitometer Technique

The fluorescent dye method for determining exchange coefficients allows only a gross average value to be obtained. By subdividing a basin into sections, some additional detail may be obtained, but the experimental values are still averaged for each subsection. To overcome some of the deficiencies in the dye technique, a photographic method was developed which promises to be more versatile, more informative and quicker than the dye routine. Further development is underway to refine the method and to correlate its results with those obtained by the fluorescent dye method.

The "photodensitometer" technique requires only a densitometer having a small field of vision and the capability of detecting small differences in the density of a positive transparency photograph. The procedural steps are

1. Photograph (preferably black and white film) the model when filled with clear water to establish a background light level. A neutral grey color strip should be included in each photo.

2. Dye the basin with a suitable water-soluble dye (Mother Stewarts bluing works well) and photograph.

3. Run the model through the selected number of tides and photograph at selected times-there is no need to stop the generator as in the fluorescent dye method.

4. Develop the photos as positive transparencies, prepare a trans-grid overlay, insert in densitometer and record meter readings at each grid point from each transparency.

5. Make calibration corrections, subtracting the readings from the background transparency from those for the final "ith" cycle and the initial "o" transparencies. The numerical average of all readings should correspond to a basin-averaged exchange coefficient.

6. Plot the coefficients at respective grid points and draw contour lines of equal concentration.

The advantages of the method over the fluorescent dye procedures are:

1. Concentration values can be obtained at points in a grid whose fineness is limited only by the size of the "eye" of the densitometer.

2. Photographs may be taken at any time, so changes between any tidal cycles may be studied; it is not necessary to stop the model to obtain the basic concentration information.

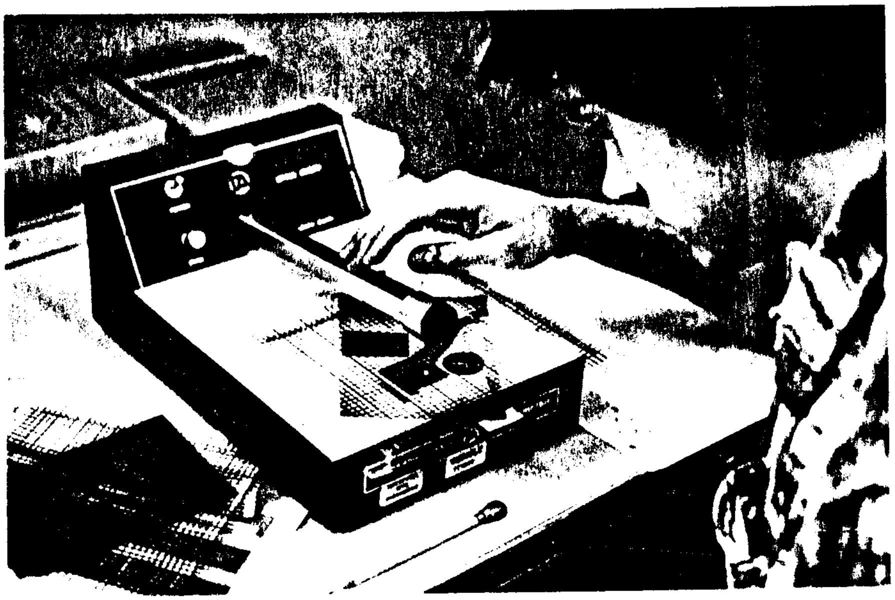
3. Contours of equal concentration can be prepared for rather detailed comparison between different runs and different physical situations. The contours provide some quantitative information on mixing in local regions which could be described before only in qualitative terms from the still- and cine records.

4. There are fewer risks of experimental error,and, therefore, fewer experimental runs are needed, so lab time is reduced.

Careful, conscientious photo/lab work is needed to prepare standardized, high-quality positive transparencies. Analysis time may be longer for processing a single run than for the fluorescent method, but fewer runs need be made, and the additional information obtained is worth any extra time required to get it. The densitometer used was Model TBX from Tobias Associates, Inc.. This machine had a digital readout of density and a 3-mm eye. The grid used was made of 5-mm squares. A photograph of the unit set up for analysis is shown in Figure 15.

PHOTOGRAPHIC TECHNIQUES

The patterns of internal circulation and mixing developed in the model marina during the ebb and flow of the tides can be observed as the model is in operation, but for subsequent study and discussions, a record



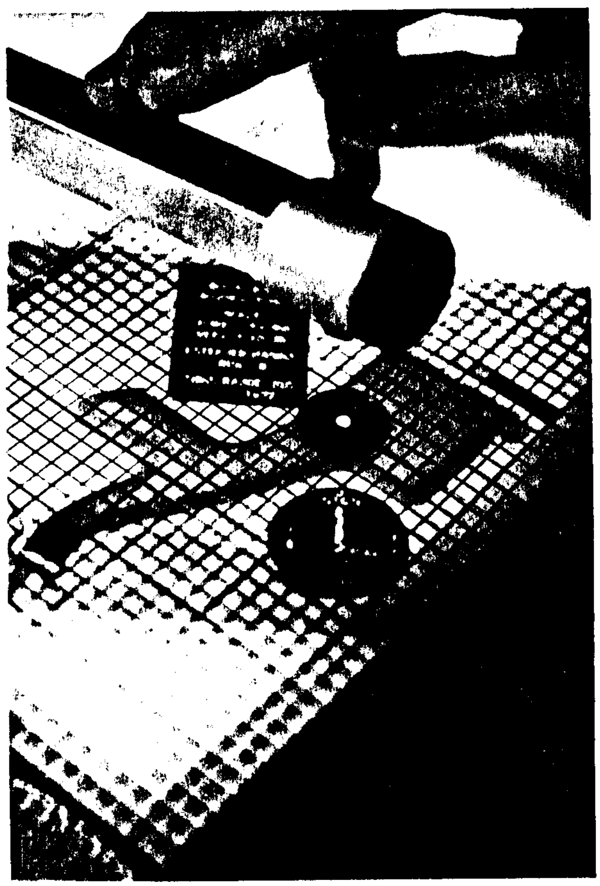
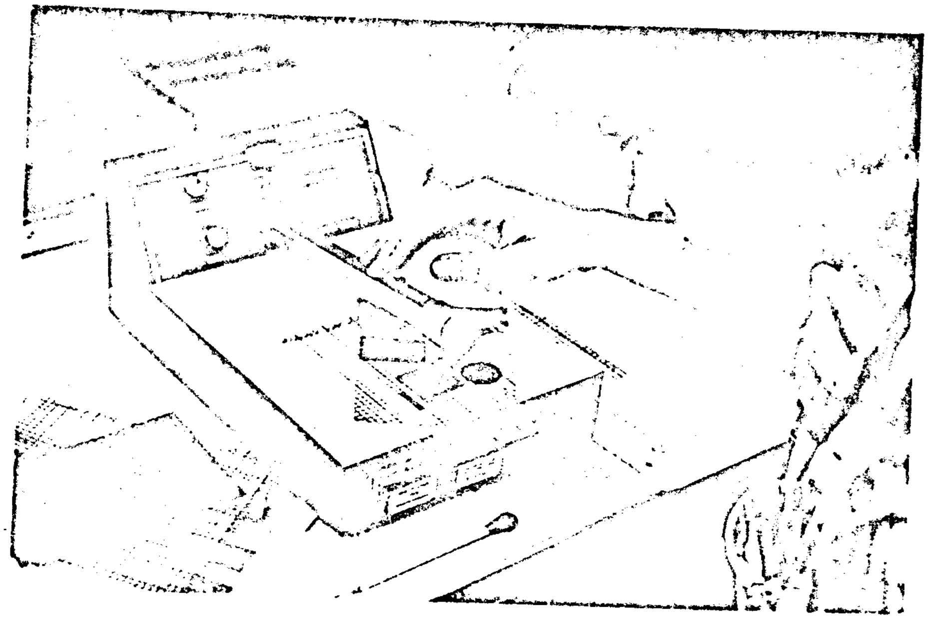


Figure 15. Photodensitometer Technique



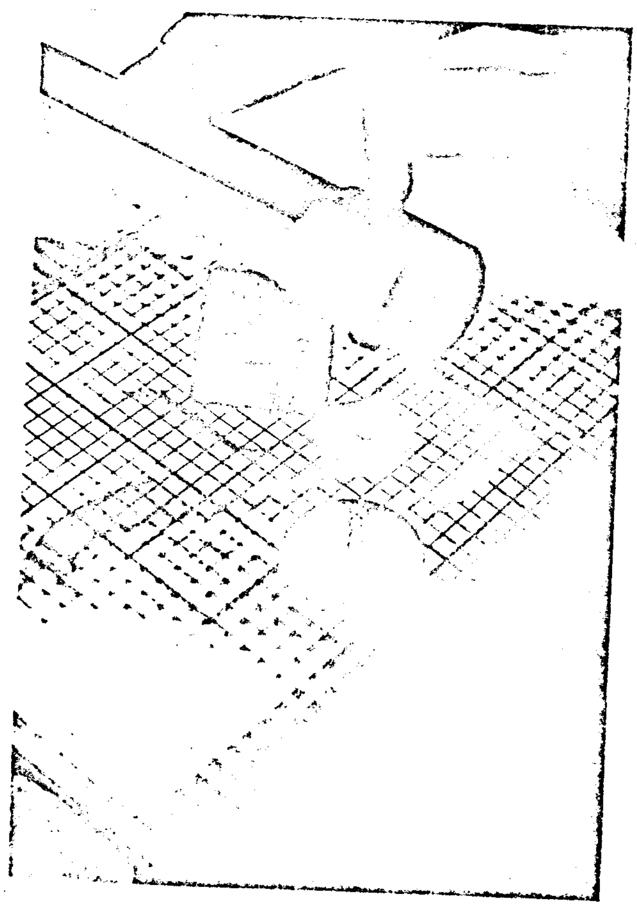


Figure 15. Photodensitometer Technique

is needed. This was obtained by using 35-mm still- and Super 8-mm cine color photography. The 35-mm record can be reviewed to check for differences between any two situations, i.e., between different times for a given planform, or between different planforms or designs; the cine record presents in a quick, convenient way the flow fields as they developed with time.

The operation of the model when set up for the photography work is the same as for the exchange coefficient determination except that a color dye replaces the fluorescent one. Mother Stewart's bluing has been very satisfactory; it has good visual and density properties and is easy to clean off painted surfaces and equipment. The average tidal range (5.9 feet) is set and the basin dyed to a suitable density with the bluing. The 35-mm camera mounted above the basin was set to record at each quarter cycle. The Super-8 movie camera was fitted with a time-lapse control set to take one frame a second, an interval that accommodated at least four tide cycles on one 50-foot roll of film. For extra visual references, small drogues were placed in the basin to mark out flow paths. A review of the 35-mm slides, along with the cine record is then made to identify the ebb and flooding currents, the regions of lighter and darker water, zones of separation, residual gyres, and the dilution of the dye with time and distance. These overall features are viewed against the exchange coefficient data in a final assessment and comparison of the hydraulic characteristics of different plans and tidal ranges.

The contour maps from the photodensitometry work provide a numerical measure of the relative densities that appear on the corresponding 35-mm slides. That is, the exchange coefficient contour map prepared for a four-cycle interval is a quantified version of the 35-mm slide for cycle 4. The slides in between the initial and final photographs used for preparing the contour map provide a record of the flow events leading to the final condition.

CHANNEL VELOCITY

Since the currents through the marina entrance are so important to the internal circulation patterns, a prediction of average velocity is made for tide cycle at a spring range for both the existing and the expanded marinas. Field measurements of the flooding current were made on August 25, 1977 from a location of the channel centerline at a height of one meter above bottom so this tide cycle was chosen for the numerical prediction.

The average velocity at a given cross section (in this case in the entrance channel) can be predicted from the principle of volume conservation which states that

$$V_e A_e \, dt = A \, dz$$

where V_e = velocity at entrance

A_e = area at entrance (width times depth)

A = planform area of basin for a given depth

dt = time interval

dz = change in surface elevation during time dt.

The depth changes with the time, of course, so the areas involved have to be computed as functions of depth. For computational purposes, graphs were prepared to express the relationship of these areas with depths. For the relatively short basin, it is acceptable to assume that the volume A dz would all flow out the entrance area A_e in a time period dt so

$$V_e = A/A_e \; dz/dt.$$

The quantity dz/dt, the time rate of change of surface elevation, can be taken from a plot of tide height vs. time. The computations are carried out in a series of small time intervals; the tide cycle used and the resulting predictions of the average velocity at the entrance for both the existing marina and for the expanded one are shown on Figure 21. Local points velocities could be somewhat higher.

EXPERIMENTAL RESULTS AND COMPARISONS

The results from the components of the study are discussed in the sequence already introduced, viz., Tidal Prism Ratio, Exchange Coefficient, and Photographic Techniques. Comparisons are made first with respect to the existing basin, then with other marinas of reference.

Tidal Prism Ratio: This factor is the ratio of the water volume between a low and a high tide to that in the basin at the high tide. The volumes were found by planimetering the elevation contours on the maps used for construction. Values obtained are shown in Figure 15 along with those of the marinas of reference, Des Moines, Penn Cove, Sequim, Point Roberts and Edmonds. No special differences are noted.

Exchange Coefficient: Values obtained using the fluorescent dye technique for both the existing and expanded versions are shown on Figure 17. Values averaged at each tide range are shown in comparison with the marinas of reference on Figure 18. The exchange coefficients for the existing marina are seen to be higher throughout the tide ranges than for any of the referenced sites. The expansion caused a drop, but its exchange coefficients still lie on the upper boundary of the referenced ones.

Exchange Coefficient Contours: Contours of exchange coefficients for a range of 5.9 feet for the existing marina are shown on Figure 19. The final position was at the high water slack for tide cycle 4. The contours show the effect of many hydraulic features involved in the flushing and circulation processes. The strong flooding jet carries along the centerline of the channel, with separation off the right side, region F on Figure 14, and a part of it curls off at A and works its way into the sub-basin, designated herein as "Comox Bay". Drogues in the field marked out these same paths, as did those in the model. The main jet, then, keeps its identity until entering the main basin, where it seemed to diffuse without setting up any defined cells, a feature observed in the field, also. A reverse flow was noted at B, Figure 14, with a very weak current along the transient boat float. A current meter dropped down from this float during a field measurement hardly registered any movement on the flood tide. On the ebb, currents moved into Comox Bay, and a weak separation zone formed along the jetty seaward of Point F. Back within the marina, there is a closed 25-contour identifying a cell, which, as will be pointed out on the photos later, is exhausted on the subsequent ebb tide.

The exchange contour map for the expanded marina, 5.9-feet range, is shown as Figure 20. The basin volume has been approximately doubled over the present volume, due to the larger planform area and to a small extent to the increased water depths, especially in the entrance channel. The expansion has introduced several important changes. The entrance now directs the main jet several degrees to right of its previous direction and the zone of the contour 35 is much broader. The jet momentum still seems to carry through to back of the basin where a 30-contour is formed. The exchange coefficients are somewhat lower than for the existing basin. There are more spots of lower coefficients in the expanded basin. The inner corners tend to be low, and the values in Comox Bay have dropped appreciably. Contours of 15 and 10 appear, whereas on Figure 19, 20 is the lowest. These zones of low values are rather small and confined to the corners.

<u>Photographs</u>: The principle circulation features identified in the marina will be discussed with reference to the photo sequences Figures 2-6 for the existing marina and Figures 7-11 for the expanded version. These figures are color reproductions of the original 35-mm slides; some detail has been

lost, so the slides and/or the cine film should be viewed for better reproduction. The code on the figure titles is "cycle/number of quarter cycles". For instance, "1/2" means the first cycle, low slack position.

The flooding current is the single most prominent feature in the circulation systems. It separates off the right hand side of the entrance channel, hugs the left hand shore, with its direction fixed by the straight, tangent length just in front of Comox Bay. Figure 5d shows this feature to the best advantage, although it is repeated at the three-quarter point on each tidal cycle. A part of this jet spins off into Comox Bay and initiates motion there. Note the red and white drogues in Figures 3d and 4a. These were released close together, yet took different paths, the red one toward the main basin and the white one curved into Comox Bay. This same response was traced repeatedly in the field with drogues set at one- and at two meters depth. The main jet keeps its identity until entering the main basin, where it diffuses without setting up any defined circulation cells. New water seems to reach the back of the basin by high water slack; as evidenced in the photos of Figures 3a, 4a, 5a, and 6a. The field drogues moved well in the narrow part of the channel, then slowed up markedly as they entered the main basin. The strip of dark blue water in the model along the right hand side of the channel as shown in Figure 5d indicates a narrow region of relatively slack water (at that tide position). This same feature was identified in the field by drogue paths, and current meter data.

At the end of 4 cycles there were regions of contrast in the basin, viz., lighter shading at the ends, a slightly darker cell in the center, and along the right hand boundary, and a blob in the entrance of Comox Bay. These features are put into numerical context by the contours of Figure 19.

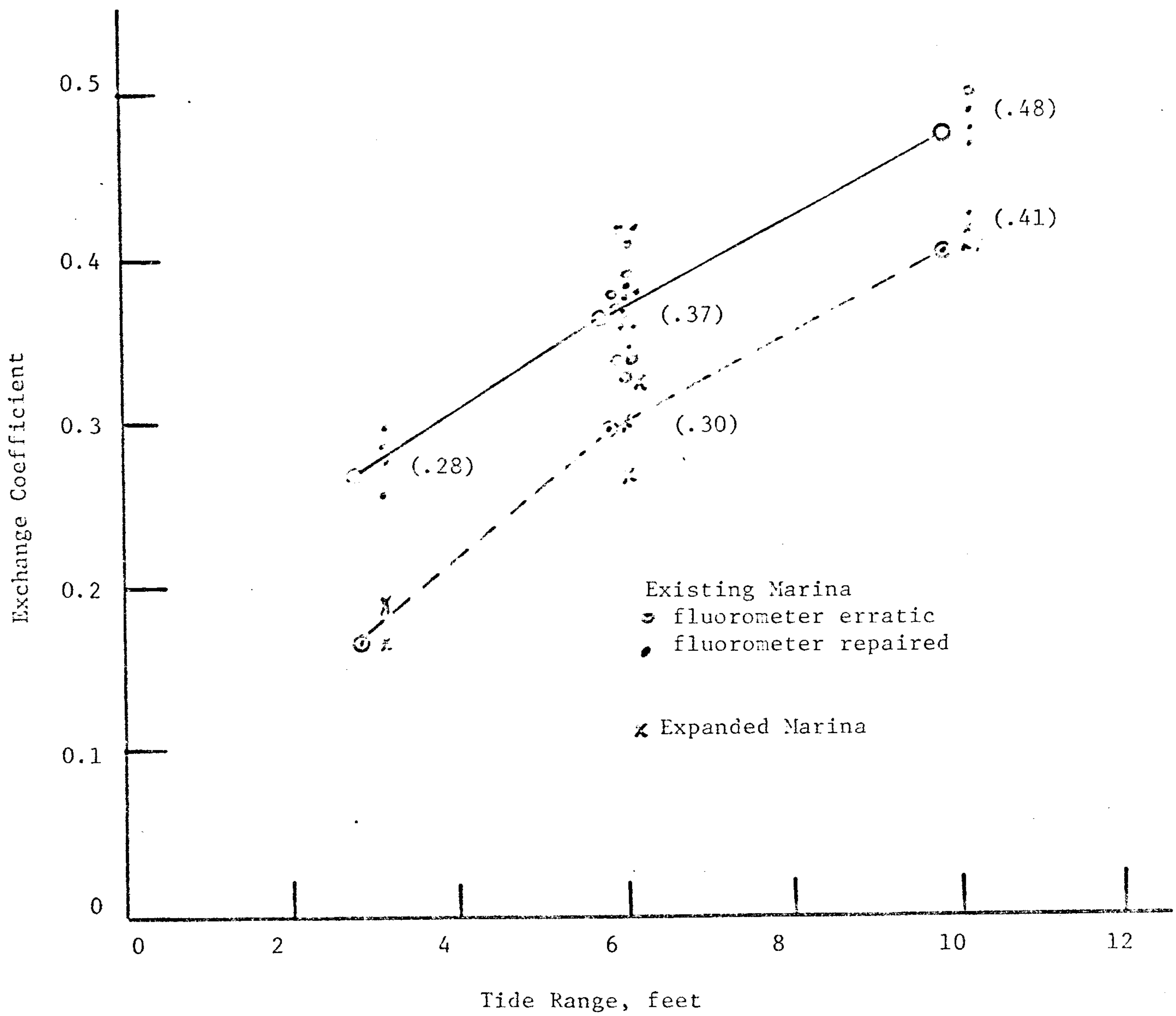


Figure 17. Exchange Coefficient vs. Tide Range, Birch Bay Marina

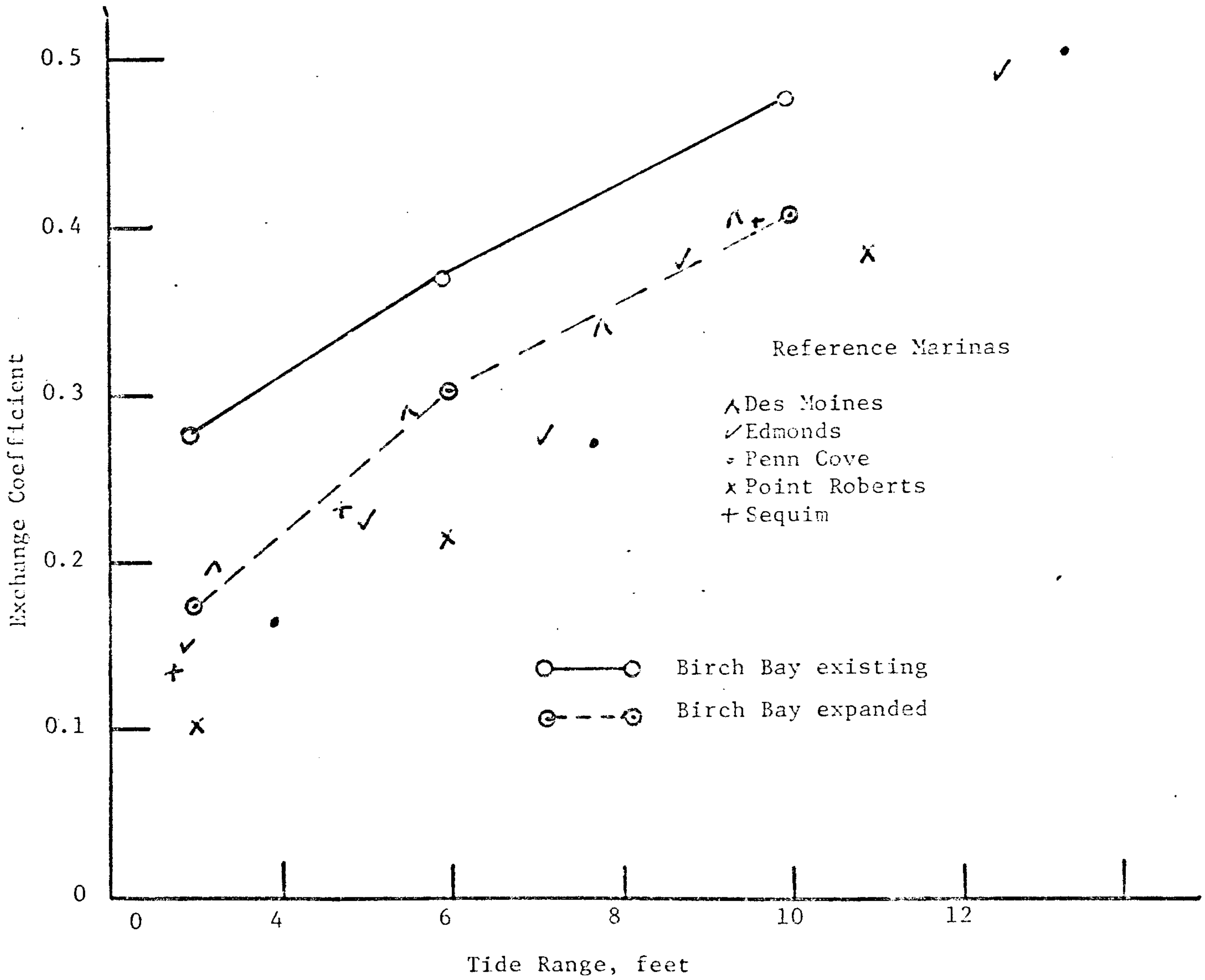


Figure 18. Comparison of Birch Bay Marinas with Reference Marinas

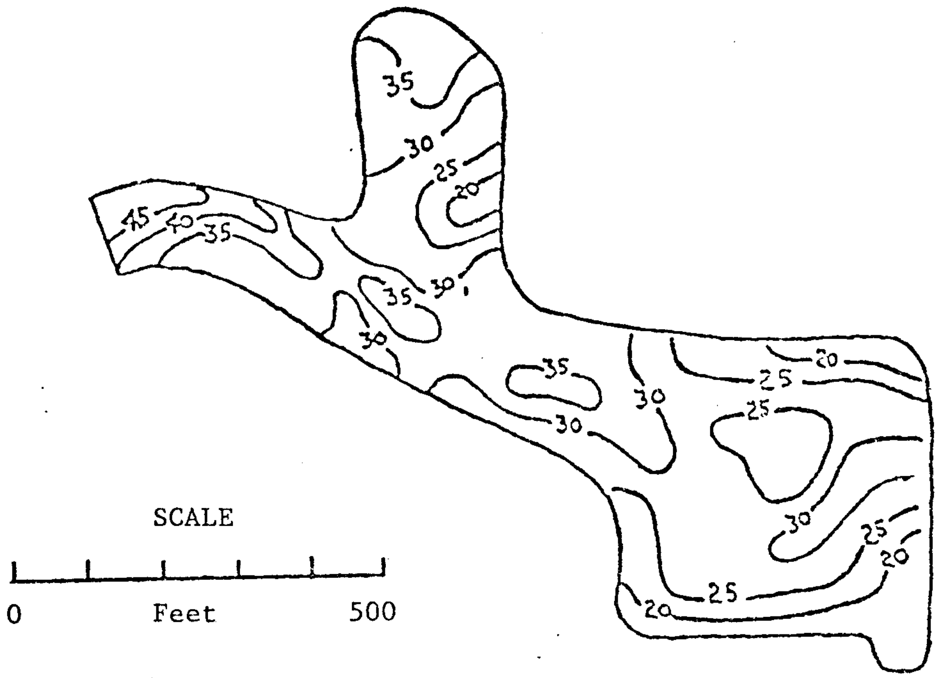


Figure 19. Birch Bay Marina, Exchange Coefficient Contours

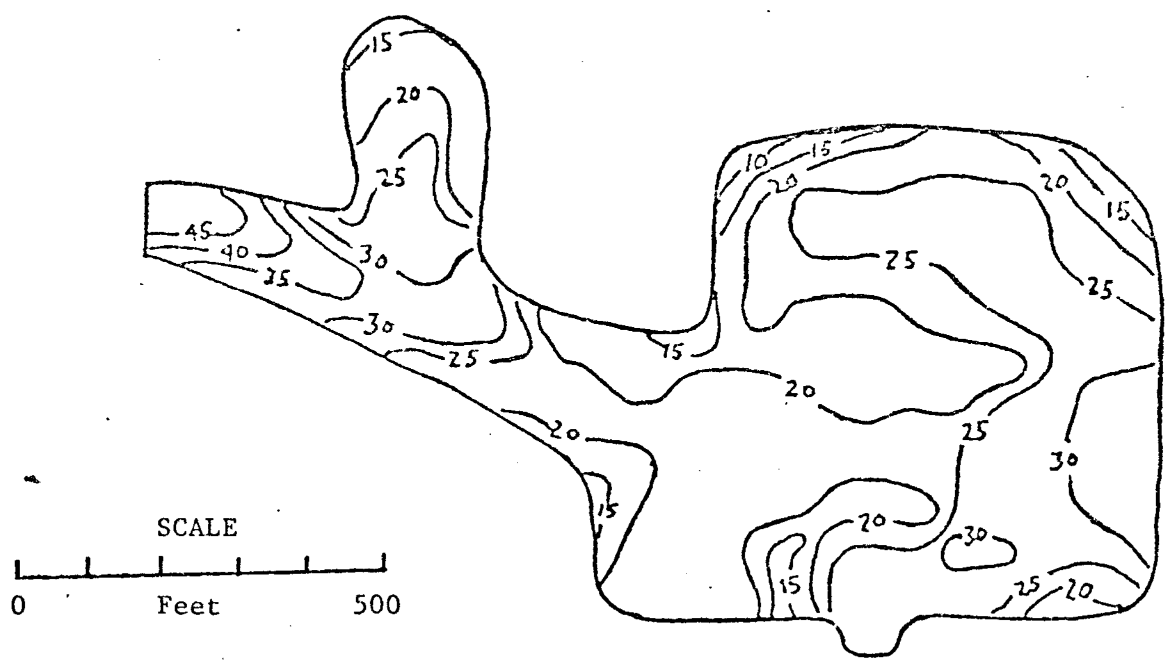


Figure 20. Birch Bay Marina Expanded, Exchange Coefficient Contours

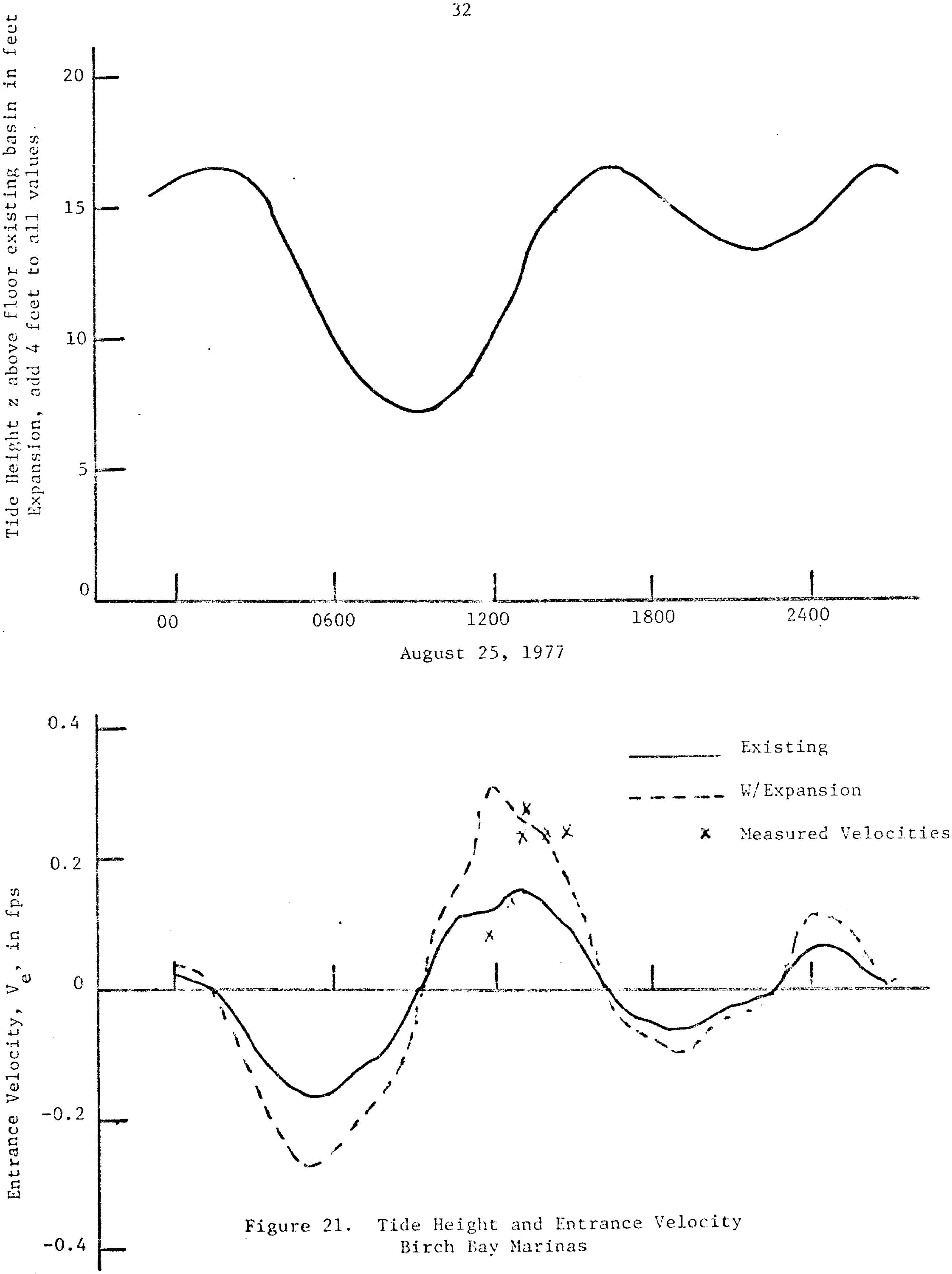


Figure 21. Tide Height and Entrance Velocity
Birch Bay Marinas

At low slack, however, as in Figure 5c, the coloring is quite uniform (well mixed) over the basin, except for a corner and along the south shore. Water moves into Comox Bay on the ebb as well as on the flood, but exchange in the northern corner is not as active as elsewhere. The qualitative features shown by the photo sequences, the strong flood jet, penetration into the main basin, and no consequential "hot" spots support the favorable conclusions already drawn from the exchange coefficient data.

After the expansion, the major features are still quite like those in the existing marina, but with some important differences. The incoming jet appears much stronger, as shown on the 3/4 tide positions on Figures 7 through 11. Less flow is turned into Comox Bay. There is a dark cell in the center of the main basin at the high water slack position, as in Figure 11a, and shown by the contours on Figure 20. However, the mixing is quite uniform by low water slack, Figure 11c, but with a dark zone on the inside corner of the main basin.

DISCUSSION OF RESULTS

The geometric reasons for the high exchange coefficients for the existing marina are:

a very direct communication to the new-water source (Birch Bay),

a narrow entrance channel and short distance (about 500 feet) from the place where the channel begins to widen to the back of the basin,and

shallow depths and favorable tidal prism ratio.

From the hydraulic point of view, the strong incoming jet provides a circulation and mixing action, with the jet separating from some boundaries and keeping its identity well into the basin. There was quite good agreement between the features observed in the field and those in the model.

It was anticipated that there would be some counterbalancing effects of the expansion on the hydraulic characteristics of the total system. On the positive side, the expansion doubles the water volume in the marina; this means the momentum through the entrance channel has increased by a factor of four, so that the stronger jet on the flood tide can penetrate into the expansion and set up favorable mixing currents. On the negative side, the distance from the widening point in the channel to the back of the basin has been increased from 500 feet to about 800 feet, with the attendant shift of the center of mass of the system farther from the entrance. The depths proposed for the completed design are greater than at present, so there is a decrease in the tidal prism ratio. The dropoff in exchange in Comox Bay appears to be related to the realignment of the flooding jet due to the revised entrance depths and higher momentum. The net quantitative change in the basin average value of exchange coefficient is seen from Figure 17 to be from 0.37 to 0.30, still on the upper boundary of the performance curve.

Figure 19 and 20 were prepared from point values of density following the assumption that the photographic film density was linearly related to color dye density. The average of point values gave exchange coefficients of 0.28 for the present marina and 0.23 for the expanded version, whereas the corresponding values from the fluorescent method were 0.37 and 0.30. A calibration correction applied to the linear assumption yielded an E = 0.27 for the expanded marina. The values on the contours shown on Figure 20 could be corrected upwards for this adjustment.

The photodensitometer method gave so much more detail than the fluorescent method that it has been presented herein, even though more developmental work is needed (and is underway) to determine dye concentrations to fit more closely a linear response, to define the response better, and to establish correlations with the background of exchange coefficient information obtained from the fluorescent technique.

CONCLUSIONS

A certain amount of subjective opinion enters into the extrapolation of hydraulic characteristics of a marina to the impact on water quality. The hydraulic model even with its limitations is an extremely useful tool in narrowing the bank of subjectivity. In this particular study of the Birch Bay site, the physical development being evaluated was an extension of an existing facility - not the construction of one totally new where none existed before. There was the opportunity to investigate the hydraulics of the existing marina in model as well as in prototype, through an associated project on water quality, fish and shellfish, so the correlation between water quality and hydraulics, though still not reduced to quantitative terms, was better than that given in other studies on regional marinas. The impact of the expansion could be gaged against the hydraulics of the existing marina, rather relying exclusively upon comparisons with marinas at other sites. The report on the water quality, fish and shellfish aspect was not available at completion time of this report, so the cross ties of the hydraulics and water quality will have to be tightened up by subsequent comparisons.

The present marina produced exchange coefficients that were higher at all tide ranges than those for the marinas of reference. The exchange appears to be with ambient water of good quality, which leads to the presumptive conclusion that the water quality in the marina should receive a good rating - it appears to be good and the marina well cared for.

The proposed expansion about doubles the water volume in the present one; the overall exchange coefficients decreased from those for the present marina, but only down to the upper boundary of those for the marinas of reference. The photodensitometry introduced in this study makes a more detailed evaluation and enumeration of exchange characteristics than the fluorescent dye method.

The waters in the corners of the expanded basin had low exchange values; rounding of these corners is recommended.

Exchange in the sub-basin (Comox Bay in this report) dropped appreciably from that in the existing configuration. The forecast condition calls for a low coefficient (about 0.2) but not lower than develops elsewhere in the model of the present marina. No structural revisions are recommended at this time. The final dredging may lead to a slightly different alignment of the flooding jet. Prediction of the effect of a few degrees difference from the distorted model is uncertain.

It is recommended that a post-construction assessment of water quality in Comox Bay be made. If circulation does indeed appear substandard, a small underwater groin or wing wall would suffice as a steering vane to intercept a section of the flooding current and direct it into the Bay as takes place now.

The drainage from the uplands now emptying into the marina through the culvert under the dike should be diverted from the expanded version. Such drainage has been designed out of the point Roberts Marina.

In final conclusion, the proposed expansion of the Birch Bay Marina should result in a performance comparable to that shown for the upper boundaries of the marinas of reference. Some local sensitive spots can be eliminated by simple rounding of corners. A contigency plan should be considered for a guide vane to direct a piece of the flood current into Comox Bay if field evaluations should show it to be necessary.

REFERENCES

Collias, E. E., and Barnes, C. A., "An Oceanographic Survey of the Bellingham-Samish Bay System," Special Report No. 32, University of Washington, Department of Oceanography, March 1966.

Lewis, L. L., "A Hydraulic Model Study of the Flushing Characteristics of the Two Alternative Small-Boat Basin Designs," M.Sc. Thesis, University of Washington, Seattle, Washington, 1972 (unpublished).

Meany, Edmond S., "Vancouver's Discovery of Puget Sound", Binfords and Mort, Portland, Oregon, 1957, pp. 210-211.

Nece, R. E., "Hydraulic Model Study, Point Roberts Marina," unpublished report, January 1976.

Nece, R. E., "Hydraulic Model Study, Sequim Bay Boat Haven," unpublished report, August 1976.

Nece, R. E., R. A. Falconer and T. Tsutsumi, "Planform Influence on Flushing and Circulation in Small Harbors," 15th Conference on Coastal Engineering ASCE, Honolulu, Hawaii, July 11-18, 1976.

Nece, R. E. and C. R. Knoll, "Flushing and Water Quality Characteristics of Small-Boat Marinas," Charles W. Harris Hydraulics Laboratory Technical Report No. 40, Department of Civil Engineering, University of Washington, Seattle, June 1974.

Nece, R.E. and E. P. Richey, "Application of Physical Tidal Models in Harbor and Marina Design," Proceedings of the Symposium on Modeling Techniques, ASCE, San Francisco, California, September 3-5, 1975.

Nece, R. E. and E. P. Richey, "Flushing Characteristics of Small-Boat Marinas," Proceedings of the Thirteenth Coastal Engineering Conference, Vancouver, Canada, July 1972, pp. 2499-2512.

Nece, R. E. and C. V. Tweedt and E. P. Richey, "Hydralic Model Study of Closure of the East Waterway Duwamish River Estuary," Charles W. Harris Hydraulics Laboratory Technical Report No. 35, Department of Civil Engineering, University of Washington, June, 1973.

Richey, E. P. and D. H. Haury, "Birch Bay Marina: Hydraulics and Water Quality," Charles W. Harris Hydraulics Lagoratory Technical Report No. 52, Department of Civil Engineering, University of Washington November 1977.

Richey, E. P., G. B. Lewis and R. E. Nece, "Penn Cove Marian: A Design Coordinating Hydraulic and Environmental Criteria, Paper No. 3, Session 5B; Hydraulics of Estuaries, 23rd Annual Specialty Conference, Hydraulics Division, ASCE, Seattle, Washington, August 1975.

Richey, E. P., and R. E. Nece, "Flushing and Mixing Characteristics East Bay Small Boat Basin," Charles W. Harris Hydraulics Laboratory Technical Report No. 50, Department of Civil Engineering, University of Washington, July 1977.

Richey, E. P. and R. E. Nece, "Lake Crockett Small Boat Basin Circulation Study," Charles W. Harris Hydraulics Laboratory Technical Report No. 33, Department of Civil Engineering, University of Washington, October, 1972.