University of Washington
Department of Civil and Environmental Engineering

FLUSHING CRITERIA FOR SALT WATER MARINAS

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Water Resources Series
Technical Report No. 42
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FLUSHING CRITERIA FOR SALT WATER MARINAS

by

Ronald E. Nece, Eugene B. Welch, and James R. Reed

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The hydraulic model studies were conducted at the Charles W. Harris Hydraulics Laboratory, and the water sample analyses were performed in the water laboratories of the Water and Air Resources Division, Department of Civil Engineering, University of Washington. The field work and the Lagoon Point model study were performed by James R. Reed, Research Assistant. Professors Ronald E. Nece and Eugene B. Welch were the co-principal investigators. Mr. Patrick M. Lee was the project officer for the Department of Ecology.

The continuing interest and consultation on marina hydraulics provided by Professor Eugene P. Richey is acknowledged with appreciation.

ABSTRACT

Water quality problems, such as noticeable densities of plankton algae and subsequent reduction in dissolved oxygen content, were observed in only one of four studied marinas. A plankton algal bloom reached at least 25 μg/ℓ chl *a* in one section of Lagoon Point Marina and was followed by dissolved oxygen content as low as 2 mg/ℓ. This occurred in one section of the poorly flushed, closed end of the marina. From these observations, and an assumed maximum plankton growth rate of 100% per day, NO_3-N as the limiting nutrient and 50% of surface intensity as optimum for light, the expected maximum steady state plankton biomass was estimated for varying mixing depths (mean depth of marina) and dilution rates. The observed plankton biomass was very close to what would be expected from a marina like Lagoon Point that has a 2.5 m mean depth and dilution rate predicted to be as low as 10% per day in some sections from a physical scale model.

From these findings, criteria are suggested such that to avoid water quality problems of this type the dilution rate should be at least 30% per day and the depth 2 m. If 1 m deeper, dilution could be as low as 10% per day, but increasing depth to avoid problems is probably not as effective as increasing dilution rate because of potentially reduced mixing depths from thermal stratification in poorly flushed deeper situations.

Physical scale models are considered to be the most reliable method to determine if dilution rates for a given marina are acceptable, because of the present inadequacy of mathematical models.

LIST OF FIGURES

I. INTRODUCTION

The objective of the work reported here is to determine to what extent tidal hydraulic flushing characteristics of enclosed small-boat marinas can be related to water quality within the marinas. More specifically, the objective is to determine how well (or if) gross flushing and/or internal circulation characteristics found in laboratory tests on small scale hydraulic models serve as indices in predicting in a quantitative manner how pertinent quality characteristics of the water within constructed small-boat harbors may vary from those of the water ambient to the marina, and which of these hydraulic parameters is most appropriate to be considered in the evaluation of small-boat harbor designs. The desired application of the results of the work is to contribute more concise criteria which can be used by regulatory agencies in evaluating and granting permits for new designs, as well as providing information which can be used in improving designs to begin with.

The present study is actually a continuation of the work reported earlier in (6). All information in this report is based on investigations of specific small-boat basins, existing or proposed, in Puget Sound, Washington. For comparison purposes, some limited data and discussion on a fresh water marina at Newport Shores, on Lake Washington, are also included. Tides considered have the ranges and semi-diurnal periodicity characteristic of the region. Of the three existing marinas studies by both field sampling and laboratory models, two are essentially rectangular in platform and one is of the "canal" type. Hydraulic data on two proposed marinas (not investigated as part of the present study) also are included in order to broaden the base for hydraulic considerations.

As mentioned previously (6), it is anticipated that results of the study could be applied both to marinas in well-mixed estuarial waters and to marinas on large rivers where 'tidal' flushing results from diurnal water level fluctuations brought on by the operation of run-of-the-river hydroelectric plants.

Water quality models require a knowledge of either gross water exchange rates or a fairly detailed knowledge of currents within the water body under study, depending upon the type of model used and the degree of detail sought. Simple, small scale physical models provide an economical method of predicting the hydraulic behavior of marina-sized coastal works. Mathematical modeling techniques so far available, despite their sophistication, still do not provide sufficient detail for the kinds of basins studied here where flow separation at the harbor entrance has a major role in setting up internal circulation patterns within the harbor (5). Relative depths-to-length scale ratios are also much larger than those used in two-dimensional estuary or coastal mathematical models (3). Because small, relatively inexpensive physical models have been found to reproduce complex current patterns in tidal marinas (7), it has been considered most expedient in the present study to continue their use. One-dimensional numerical models may more readily be adapted to marinas formed of systems of linked dredged canals; from a water quality standpoint, a major problem remaining in the numerical models of pollutant transportation in such marinas is the selection of appropriate diffusion coefficients (2).

Attention has been kept, therefore, on seeing if any obvious empirical relationships exist between the simplest measurable hydraulic parameters (and if they can be identified in terms of basin geometry) and apparent consequences on water quality. Emphasis on water quality in this study is not on developing mechanisms for predicting absolute measures of water quality, but rather on seeing if empirical linkages can be found between the gross hydraulics of the basin and relative differences between the quality of the water within the marina basin and that of the ambient, external 'sea'. In the text report the hydraulic and water quality aspects are first treated separately, and then are considered together in Chapter V.

II. MARINAS STUDIED

The three marinas for which water quality sampling has been performed in the field are those at Des Moines, Edmonds, and Lagoon Point. Data from hydraulic models only of proposed marinas at Lake Crockett and Penn Cove are also included in this report. Locations of the five projects are shown in Fig. 1.

Hydraulic data and water quality measurements made during calendar year 1973 at Des Moines and Edmonds were reported in (6), along with detailed descriptions of these marinas. Under the grant of the present study, additional field sampling was carried out at Edmonds, and hydraulic model and field sampling data were extended to the Lagoon Point Marina. This latter project was selected in order to obtain as wide a range in hydraulic performance as possible among the Puget Sound marinas studied; the Lagoon Point Marina is of the dredged-canal type, and as a consequence has different hydraulic characteristics than do the other marinas studied because of major differences in geometry. In this report a brief description of each marina is given, with most attention to Lagoon Point because of its different configuration.

In the hydraulic models, each marina was tested at the semi-diurnal tidal period of 12.4 hours. Mean tidal ranges (11) at the five sites are listed in Table I. None of the sites have any natural fresh water stream inflow.

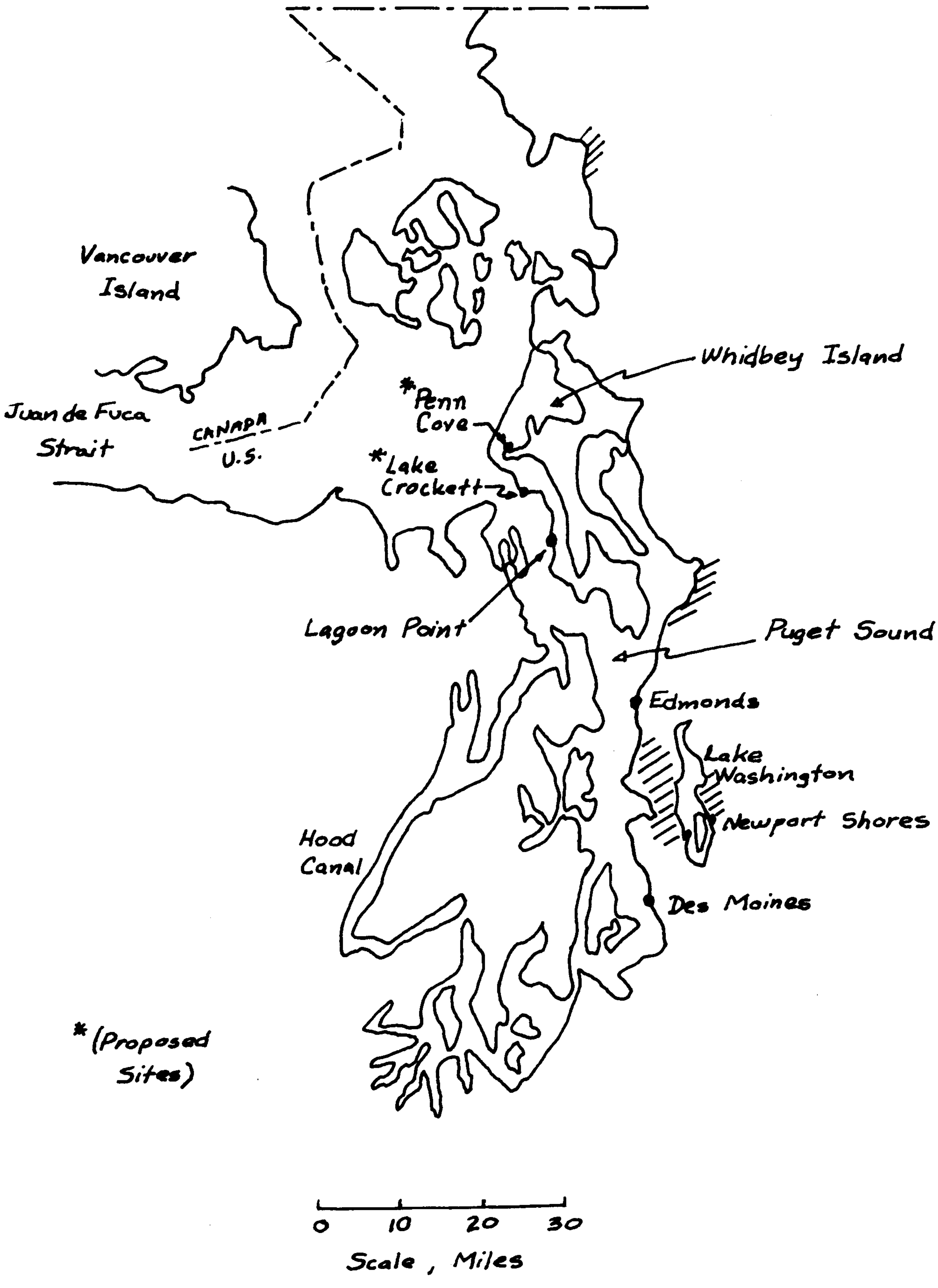

Figure 1 - Locations of Marinas Studied

TABLE I

Mean Tidal Ranges at Marinas Studied

Marina	Range, Feet
Des Moines	8.0
Edmonds	7.2
Lagoon Point	5.6
Lake Crockett	5.6
Penn Cove	7.8

Des Moines Marina

The planform geometry of the marina is shown in Fig. 2, on which dredged depths as depths below mean lower low water (MLLW) are indicated. The marina has a surface area of approximately 20 acres, with a mean depth of -12.6 MLLW. The floating piers which provide berths for 682 boats are not shown on the drawing. Most of the floating piers have protective sheds, so that approximately 25 percent of the total water surface within the marina is shaded. Comparison of drogue tests run in the field and in the hydraulic model (6,7) showed the floats to have negligible effect on current patterns within the marina. Pollution sources for the marina are two storm drains serving residential areas to the east and emptying into the basin, and drains from the marina parking lot. Des Moines Creek, which during a 'dry' summer may average a discharge of less than 2 cfs, enters Puget Sound about 600 feet north of the marina entrance.

In the hydraulic tests, average flushing rates were determined as a whole for the entire marina basin inside the well defined entrance between the rubble mound and timber pile breakwaters indicated on Fig. 2.

Edmonds Marina

The layout of the marina is shown in Fig. 3. The two marina basins, having a combined surface area of approximately 25 acres, are dredged to -12 MLLW. Floating piers shade approximately 25 to 30 percent of the surface; there are 825 boat berths. Locations of the water quality sampling stations are indicated.

Model tests treated the north and south basins separately, although neither of these was further sub-divided in the flushing tests; the dashed lines between timber pile and rubble mound breakwaters delineate the areas treated in the flushing tests. Drains from the marina parking lot empty into the basin; the outfall from the municipal primary sewage treatment plant empties into Puget Sound just north of the marina, as does a city storm drain; a 6-foot storm drain which also carries the flow of a creek empties just south of the marina. During periods of field sampling there were generally low flows in all creek and storm drains. Slight stratification effects due to spring runoff from the nearby Snohomish River are considered to have negligible effect on currents in the marina.

Further details on the Edmonds and Des Moines marinas are given in (6).

Lagoon Point Marina

The marina layout is shown in Fig. 4. In contrast to the Des Moines and Edmonds marinas, Lagoon Point is a residential development. The Marina canals have been dredged from an existing marsh on Lagoon Point, on the west side of Whidbey Island; the spoil material has been used for homesites which will have small private docks in the canals. The west canal was dredged in 1970; the east canal was breached through to the inner entrance in 1974. By May, 1975, there were no homes on the east canal, and a small

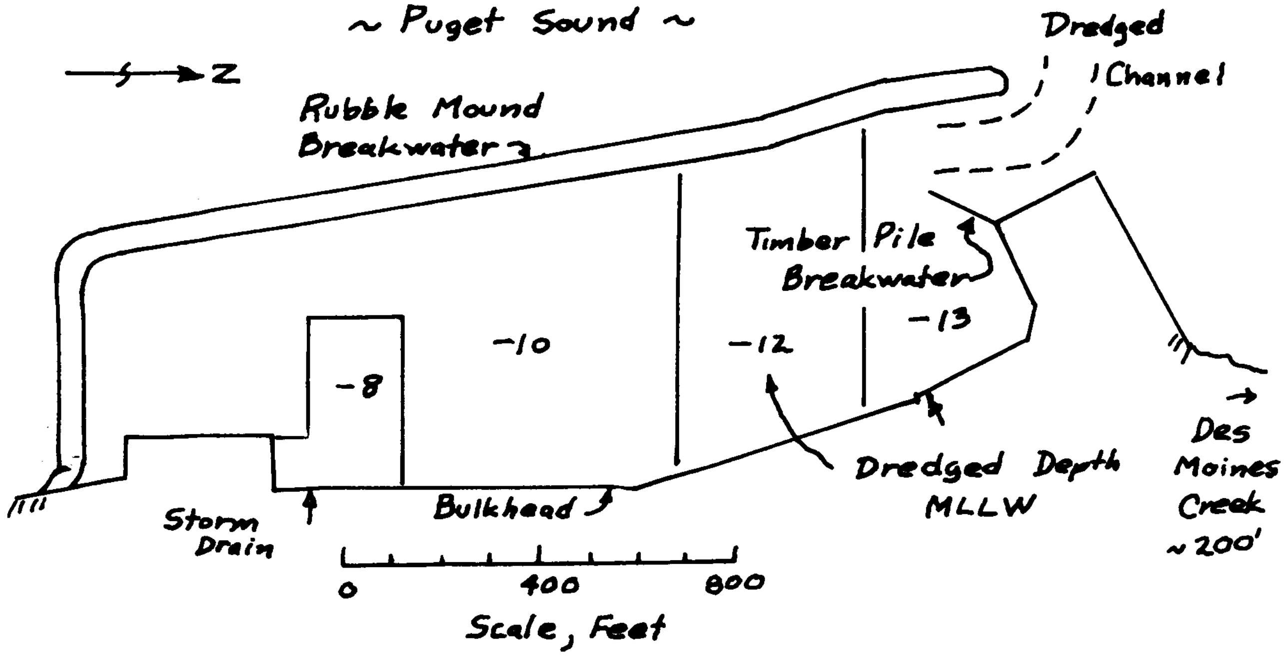

Figure 2 - Plan View of Des Moines Marina

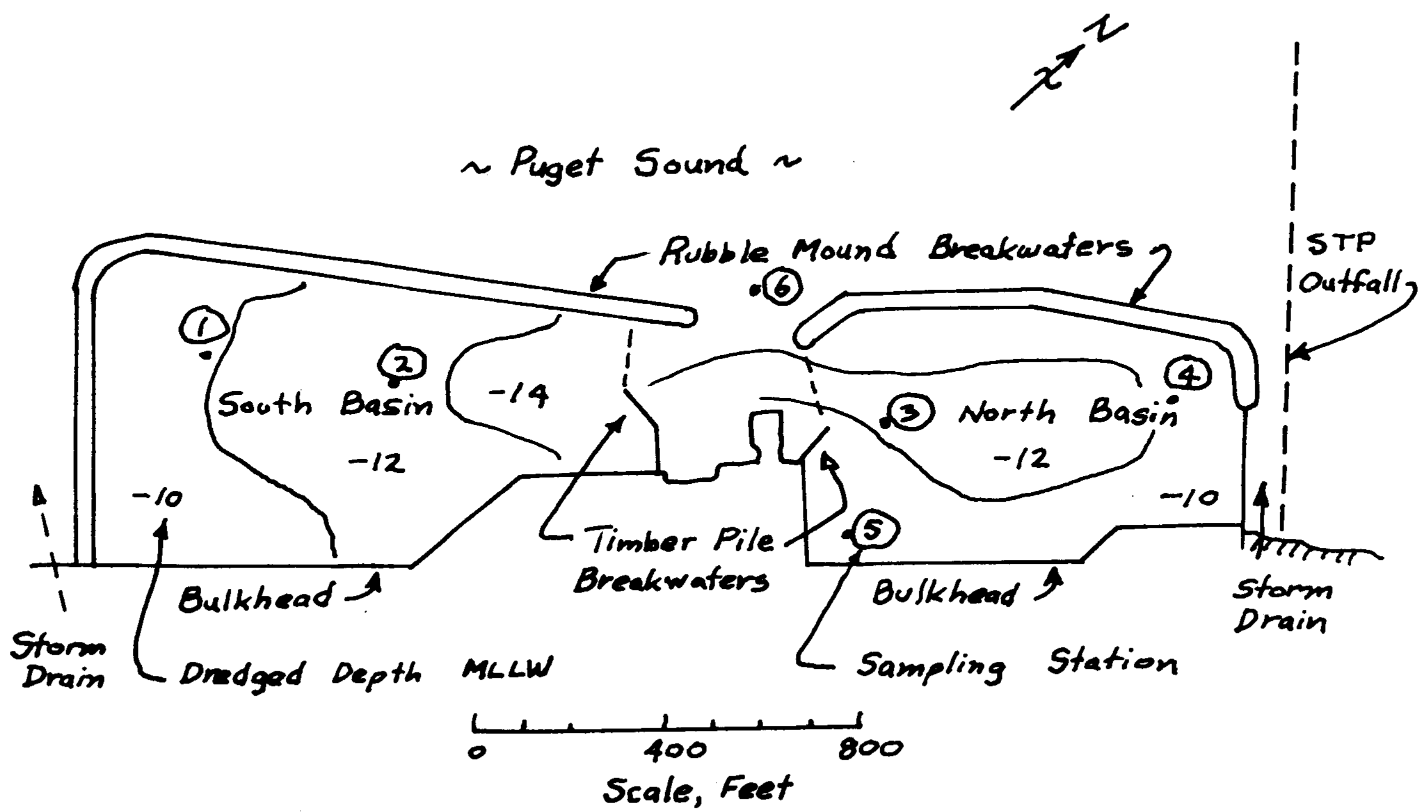

Figure 3 - Plan View of Edmonds Marina

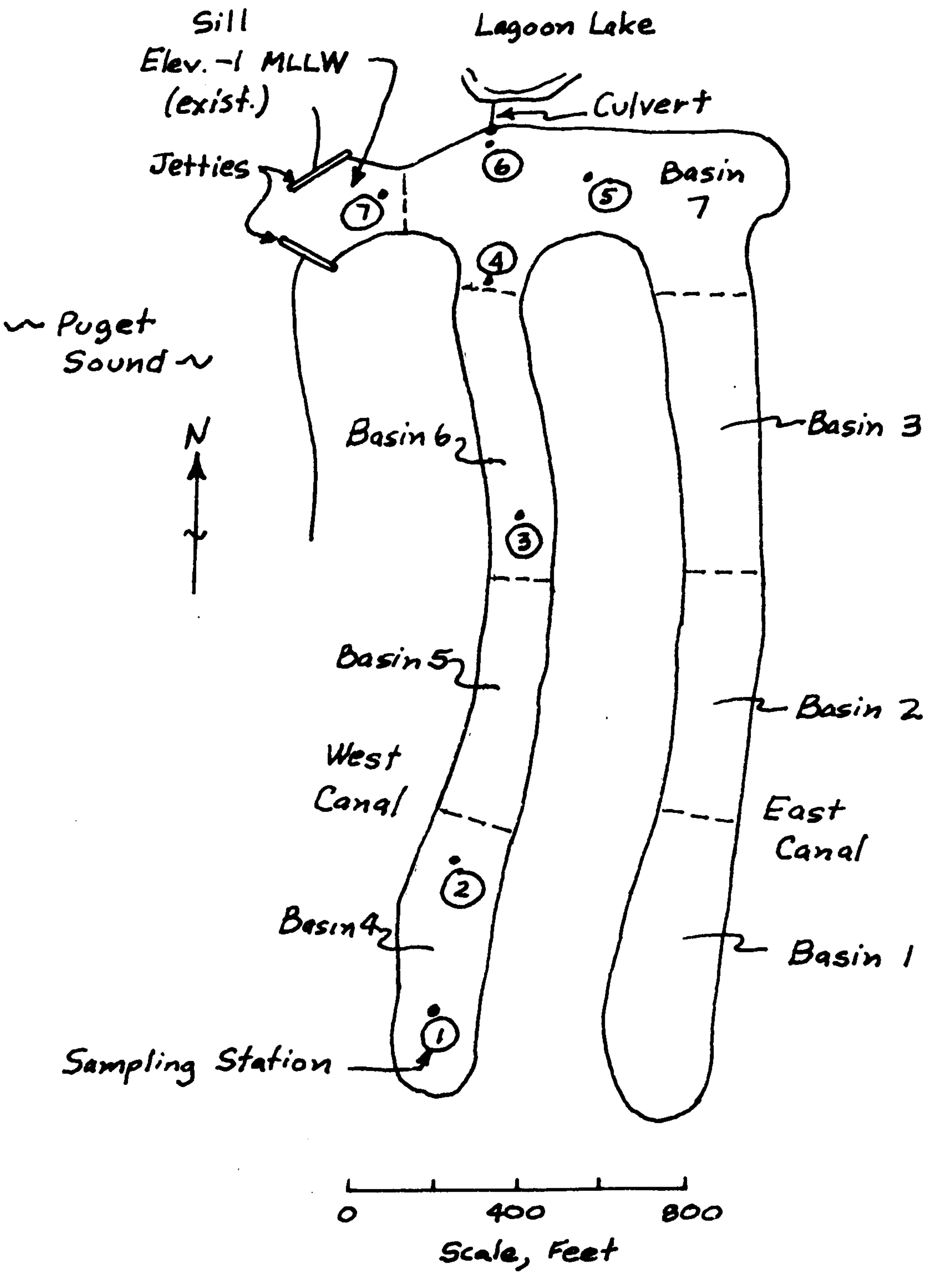

Figure 4 - Plan View of Lagoon Point Marina

number on the west canal, mostly near the closed end. There is no sewage collector system.

Existing Lagoon Lake, a brackish water tide pond of approximately 4-acre surface area, empties through a tide gate via a 3-foot culvert into the inner entrance channel. This pond, although surrounded by homes which are not on a sewage system, is considered to have negligible effect on the marina water quality; discharges from it are too small to have effect on the marina hydraulics (also checked by field observations), and the lake was not incorporated in the hydraulic model.

The surface area of each of the 2000-foot long canals is approximately 7 1/2 acres. Nominal design depth is -5 MLLW, with dressed side banks of 1:2 slopes; actual centerline interior depths range between -13 and -5 MLLW. The existing sill inside the jetties is at elevation -1 MLLW, so that at low water on larger tide ranges the marina basin is uncoupled from the exterior Puget Sound and the discharge is by gravity flow over the sill. Therefore, the Lagoon Point marina has two main configuration differences from Edmonds and Des Moines: (1), the long, narrow canal planform as opposed to a basically rectangular planform; (2), an entrance significantly shallower than the basin interior (all other marinas considered in this study have entrances as deep as, if not deeper than, the interior basins).

Figure 4 shows the seven sub-divisions of the marina used for evaluating respective tidal flushing coefficients; three sections were used in each canal to determine mixing, or exchange, gradients along the canal. The model tests were run without attempts to simulate wind effects. The north-south orientation of the canals, on an exposed lowland, does provide opportunity for wind effects on water circulation. The authors have observed wind effects on the travel of surface floatables; limited drogue data which have been reported also indicate wind effects (4). Prevailing northerly winds in the summer tend to deposit floatables at the closed south end of a canal, but it is considered that wind-induced currents (except close to the surface) are small with respect to tidal currents for average and larger tide ranges.

Field sampling station locations are shown in Fig. 4.

Lake Crockett Marina

Details of the hydraulic model studies of a proposed small boat basin for Lake Crockett, Whidbey Island, are given in (9). The proposed marina basin has a surface area of approximately 25 acres, with a dredged depth of -12 MLLW. The planform layouts of two possible entrance configurations, 'A' and 'D', are shown on Fig. 5. Exchange coefficients were determined for the east and west 'lobes' of the rather kidney-shaped basin.

The configurations tested had the boat entrance channel taking off from the existing Keystone Harbor, so that the marina basin did not have direct exchange with the ambient water as in the case of the Des Moines and Edmonds marinas.

Penn Cove Marina

Details of a proposed marina on Penn Cove, Whidbey Island, are given in (8); the planform of a preliminary design based on hydraulic model studies is shown in Fig. 6. The marina basin has a surface area of approximately 15 acres; the hydraulic model studies determined exchange coefficients for the three sub-sections of the basins which have design dredged depths of -6, -8, and -10 MLLW, respectively, proceeding from the closed end toward the entrance channel of -10 MLLW. The Penn Cove Marina, relative to others investigated, is of intermediate depth.

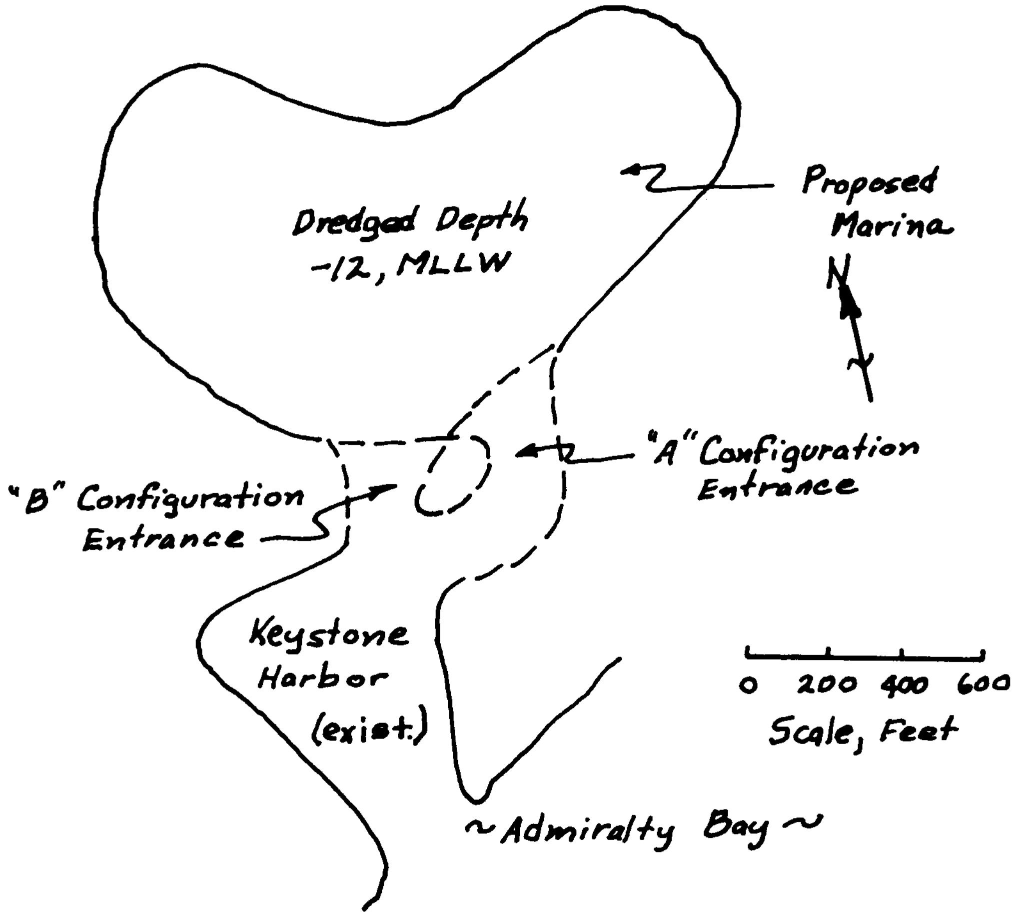

Figure 5 - Plan View of Proposed Lake Crockett Marina

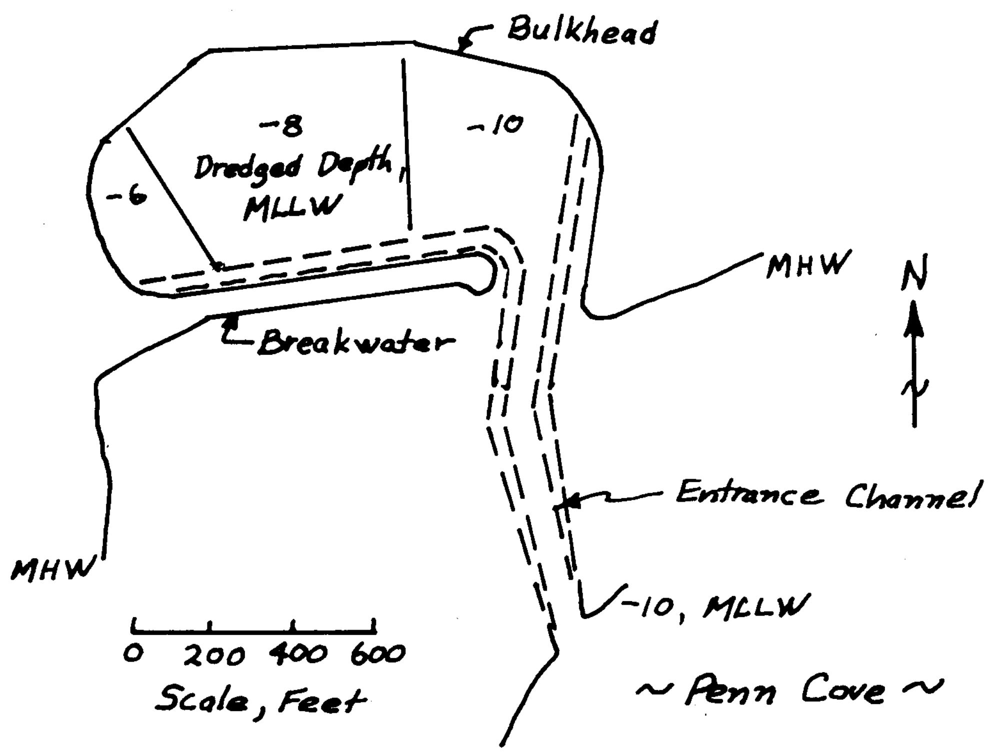

Figure 6 - Plan View of Proposed Penn Cove Marina

III. HYDRAULIC MODEL STUDIES

A. General Procedures

The laboratory basin used for the model studies had an overall plan size of 8 feet by 12 feet, with an 18-inch working depth. The constant amplitude, constant period tides were produced by a tide generator which was a variable-elevation waste weir, driven by a small motor through appropriate gear reducers and a Scotch yoke mechanism to obtain harmonic motion, and fed by a constant-rate water supply. Tide ranges and mean water levels could be adjusted by cams and threaded rods, respectively, on the weir drive mechanism; the variable speed gear box gave provision for a change of period. Model tides have been verified to be very nearly sinusoidal.

All models tested were constructed using a 10:1 distortion ratio between horizontal and vertical dimensions, and adoption of the usual practice of equal Froude numbers in model and prototype led to the particular scale relationships in each model. The basin, operated with a single working fluid without any stratification, is restricted to models simulating well-mixed water bodies. Both the low Reynolds numbers in the model and the distortion between horizontal and vertical scale nullify equivalence of local diffusion characteristics. The models do produce similarity of depth-averaged currents, and as convective transport is of much greater consequence in both the models and protype situations tested than is diffusive transport, the use of a tracer dye as a means of measuring water exchanges in the models was satisfactory. Effects of wind stress were not simulated.

Flushing rates were determined with the use of Rhodamine-WT, a conservative, fluorescent tracer dye whose relative fluorescence is an index of its concentration. Changes in the spatial average dye concentration within the marina basin or within various sub-divisions in the basin over a number of tidal cycles allowed the gross flushing rate of the basin segments with ambient water to be determined. Dye concentrations were measured with a Turner Model 110 fluorometer. The dye's fluorescence is temperature sensitive and decays when exposed to bright sunlight (12), so care was taken in test procedures to eliminate these variables. Because the fluorescence is also reduced ('quenched') by free chlorine which might be present in the city water used in model tests, a sodium thiosulfate ($Na_2S_2O_3 \cdot 5H_2O$) solution was routinely added to the water influent to the model, with about 2 mg of sodium thiosulfate per liter of water required to counteract a chlorine content of 0.4 ppm.

Flushing, or exchange, tests followed a routine procedure. A temporary barrier separated the basin from ambient water at high tide level in the model basin. Dye was mixed into the marina basin, the basin waters allowed to become quiescent, and spatial average samples taken by syringe. For the Lagoon Point model the temporary barriers dividing the canals into segments were re-installed prior to this step to insure a uniform distribution of dye throughout the entire marina, and initial samples withdrawn from each basin segment. The temporary barrier(s) were then removed, the tide generator started simultaneously, and a number of tide cycles were run, after which the generator was stopped at high tide and simultaneously the temporary barriers were replaced. The basin(s) were then mixed thoroughly, and the spatially averaged samples removed. At least two runs were made for each marina configuration -- tide range combination.

The average per cycle exchange coefficient, which indicates the proportion of water in a marina basin or basin segment which is exchanged (flushed out of) with ambient water during each tidal cycle is defined by the equations

$$E = 1 - R$$

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.

For the Lagoon Point model, $i = 4$.

The exchange ratio calculated by the tidal prism method was also calculated for each case. The tidal prism approach assumes the basin to be thoroughly mixed with ambient water during each tide cycle, yielding an optimum mixing condition. This ratio is defined as

$$\text{Tidal Prism Ratio (TPR)} = \frac{\text{(Basin Vol. at High Tide)} - \text{(Basin Vol. at Low Tide)}}{\text{Basin Volume at High Tide}}$$

where the numerator is known as the "tidal prism." Use of the tidal prism ratio, despite its acknowledged shortcomings in estuaries in general, is considered rational for comparing flushing of the small marina harbors communicating freely with ambient waters and not being affected by freshwater inflows.

B. Lagoon Point Marina Model

The model was constructed using plywood as the major structural element; canal bottom and bank contours were formed of a mortar-cement lining, on screening attached to plywood templates. All surfaces of the 'working' part of the model which were in contact with the water were coated with marine paint. The entrance section was constructed with an elevation of -5 MLLW as the highest elevation; this configuration coincided with plans of the developer (circa January, 1975) to deepen the inlet by dredging. A paint-covered modeling clay insert was provided to simulate the sill (existing as of May 1975) having the high elevation of -1 MLLW. This removable insert provided capability of testing the model with two inlet configurations; both were used in the tests. Pertinent scaling relationships for the model are listed in Table II.

Table II

Model Scale Relationships - Lagoon Point Marina

Quantity	Model Dimension	Prototype Dimension
Horizontal Distance	1	400
Vertical Distance	1	40
Velocity	1	6.32
Time	1	63.2
Tidal Cycle Period	11 min. 47 sec.	12.4 hrs

C. Flushing Data from Model Studies

Tidal flushing data for the various marinas studied are shown in Fig. 7. All values shown on Fig. 6 are average values for the respective marina basins; no attempt is made here to consider details of interior circulation patterns and resulting variations in local exchange rates at different points within the marina basins. Some of the other hydraulic studies cited have concerned effects of marina geometry upon interior circulation and flushing details, with emphasis on the angular momentum of flood flows in marinas with eccentric openings.

The exchange coefficient, E, is essentially the same over the range of tides tested for almost all marinas tested. Because depths in all marinas are much the same, and mean tide levels do not vary markedly over Puget Sound, the tidal prism ratios (TPR) are also quite comparable; Lagoon Point, the shallowest of the marinas, does have significantly higher TPR values. A third parameter, a "flushing efficiency," defined as,

$$\eta = \frac{E}{TPR} \times 100, \text{ percent}$$

is also given on Fig. 7. This efficiency compares what the tidal exchange is within the enclosed body of water compared to the exchange predicted by the simple tidal prism theory.

Edmonds and Des Moines marinas show comparable flushing characteristics, with high efficiencies over the larger tide ranges. Des Moines, which has the greatest value of η at the low tide range, has a direct opening from the basin to Puget Sound. The decreased η values for Edmonds at the average tide condition, and values also lower than at Des Moines for the smallest tide ranges tested, are associated with the effects of the central, or 'inner' harbor, separating the two marina basins from Puget Sound.

Angular momentum effects, engendered by separation around the breakwater entrances on the flood tide, can produce these swings in behavior.

Values of η greater than 100 percent deserve some comment. It has been observed in some model situations, and confirmed by field observations at Des Moines, that there can be some water leaving the basin through part of the marina entrance over a portion of the flood tide, producing an actual water exchange greater than that predicted by the tidal prism theory. Again, internal angular momentum effects play a part.

The proposed Penn Cove Marina had a short entrance channel, which is largely responsible for the lower η values at the smaller tide ranges. This feature is emphasized in the two data points given for the proposed Lake Crockett Marina. Exchange (and hence, η) values for Lake Crockett apply to the marina basin. Model studies showed that much of the water exhausted on the ebb tide remained within Keystone Harbor instead of escaping to Admiralty Bay, and then returned to the marina on the following flood and reducing the effective exchange. The marina then did not have direct contact with exterior waters, where in all the other cases studied the water leaving the marina was carried away by tidal currents so that 'new' water entered the basin on the flood. (This is the situation assumed in the simple tidal prism concept).

It is clear on Fig. 7 that the canal-type Lagoon Point Marina has the lowest flushing efficiencies, as expected. First order non-mixing tidal excursion calculations (not incorporated in this report) predict that much of the water in the closed ends of the marina would never leave the basin.

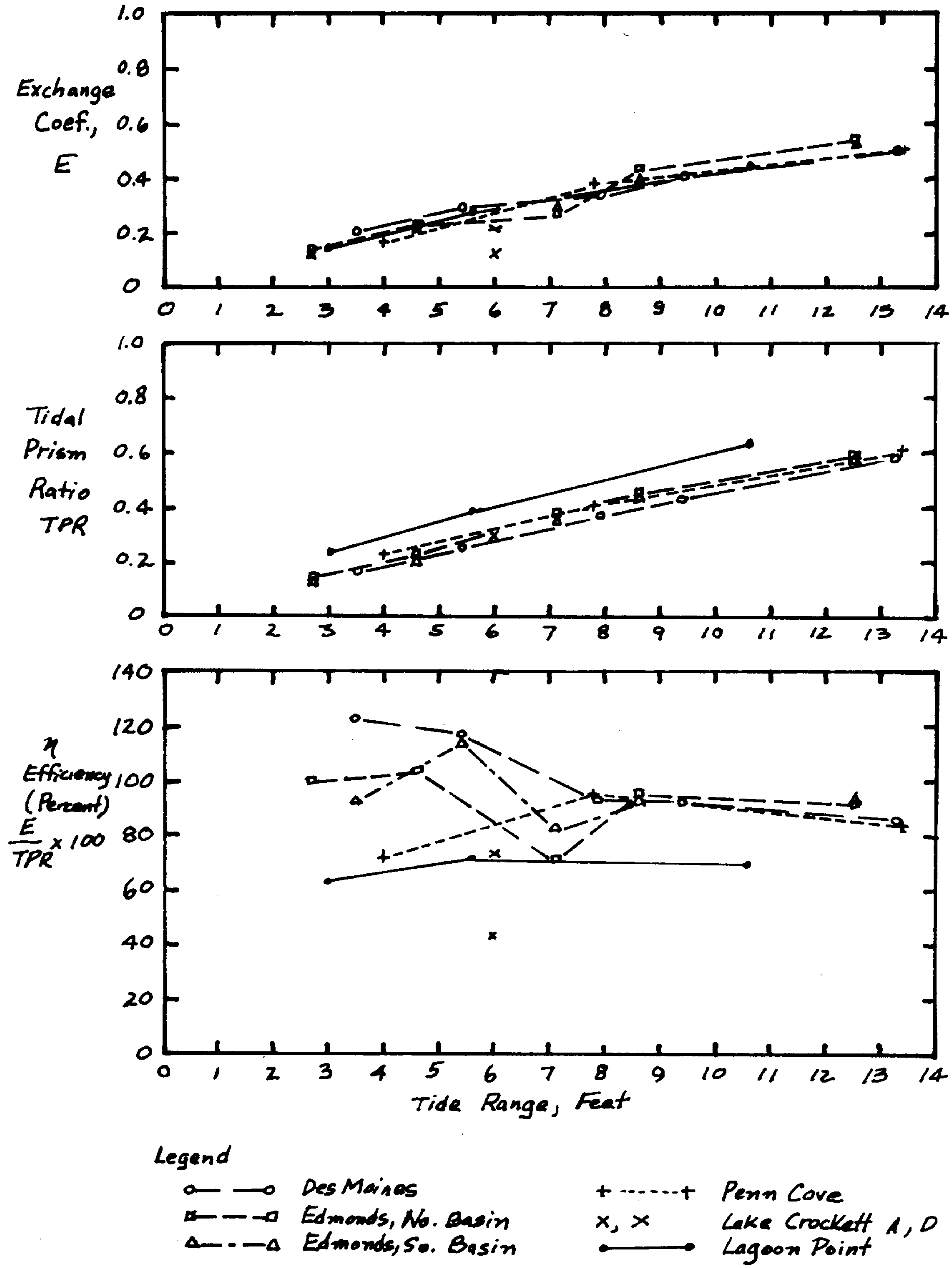

Figure 7 - Flushing Characteristics of Various Puget Sound Marinas

Flushing characteristics of Lagoon Point are examined in more detail on Fig. 8. Although the tests gave local basin values of E for each of the seven sub-divisions shown on Fig. 4, for tide ranges of 3.0, 5.6, and 10.6 feet, and for the existing (May 1975) entrance and for a proposed entrance with the existing sill removed and the entrance dredged to -5(ft) MLLW, only three sets of average E values are given on the figure. These are for the entire marina, for the entire west canal (basins 4, 5, and 6, with and without the sill), and for the average closed-end section performance for each canal (basins 1 and 4, with and without the sill). In all runs, there was a continuous decrease in exchange coefficient from the entrance to the closed end, in each canal. Exchange coefficients dropped to about 0.01 at the closed end at the 3-ft (neap) tide range.

The presence of the sill had no noticeable effect on E values for the entire marina, hence only one set of curves is shown. For the canal sections, exchange was somewhat improved in the absence of the sill as surface circulation patterns in the entrance area (basin 7) became less dominant. The model was also surprisingly, but consistently, very sensitive to small differences in temperature between water in the marina and ambient to it; canal exchange coefficients were increased when ambient temperatures were of the order of $0.2^{o}C$ to $0.5^{o}C$ below water temperatures within the basin. The apparent explanation, which could not readily be checked by dye observations, is that the entering water, after flowing over the sill at the constricted entrance, flowed beneath the interior water and into the canals, hence increasing exchange there. It seems surprising that this may be the case because density differentials would be very small, but the Lagoon Point model was the only one of those listed having an

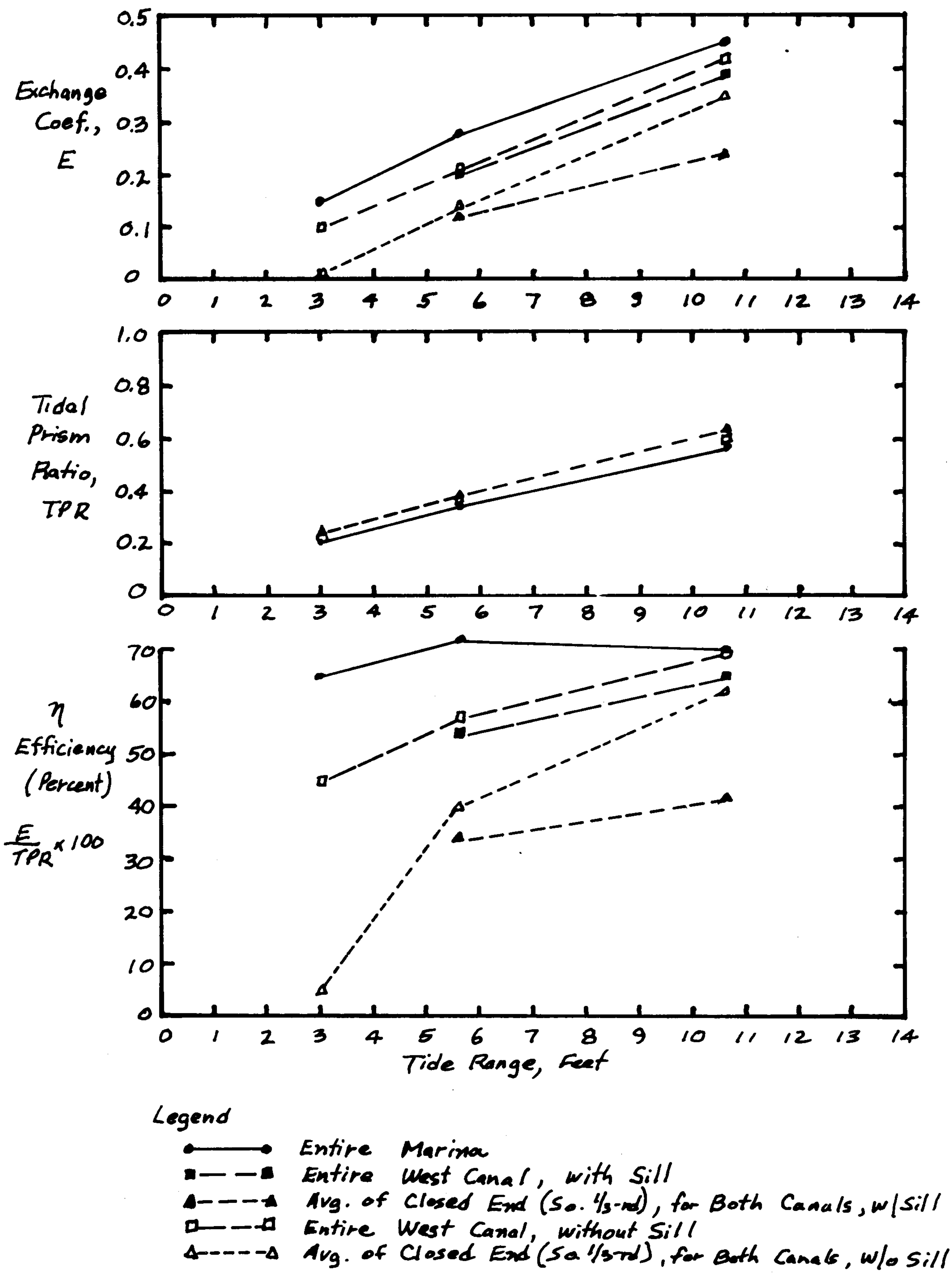

Figure 8 - Flushing Characteristics of Lagoon Point Marina

entrance sill and being also sensitive to temperature gradients across the entrance. This behavior could be possible in the field, although again measured temperature differentials there have been small. The values given in Fig. 8 are averaged over all the runs; in almost all cases, however, the spread of measured E values was within $\pm$ 10 percent of the average value given.

Calculations in Chapter V are based on local values of E for the respective separate basins most representative of the field sampling station locations.

IV. WATER QUALITY SAMPLING

Parameters Sampled

Water quality parameters sampled routinely were Chlorophyll a, dissolved oxygen, temperature, nitrate, pH, and coliform concentration. Conductivity and Secchi disk readings were also taken, the latter as a turbidity measurement.

Measurement of chlorophyll a provides an index of the total biomass in the water column. Increased abundance of marine algae can greatly affect water quality. In the absnece of light a large respiring and decomposing biomass can deplete significantly the oxygen content of water. Since algal growth in Puget Sound is largely controlled by light limitation, increased detention time in shallower areas such as marina basins could result in undesirable increases in the biomass. The chlorophyll a content then provides verification if increased detention time (low tidal exchange rate) does result in accumulation of algal biomass.

Dissolved oxygen and temperature profiles provide evidence if increased water detention time results in greater thermal stratification and if more algae and reduced tidal exchange result in decreased oxygen content near the bottom, associated with the decomposition of algae which have sunk through the water column.

Nitrate concentrations provide an indication if greater nutrient uptake by algae is occurring in the marina as a result of increased water detention time. The pH of the water can be used as a further indicator of algal growth; as carbon dioxide is consumed in the photosynthetic process the pH increases.

The total coliform concentration is an index of the response of a marina to possible pollution sources which might lie within and/or near the marina. Increases in coliform concentrations may occur if flushing rates are reduced and/or if human pollution sources increase. The coliform group of bacteria is used as the standard indicator of fecal contamination.

Sampling and Analysis Methods

The effort was made to begin sampling near or shortly after lower low water slack tide, so that the effective detention time for water within the marina was maximized. In order to retain reasonable similarity of tidal conditions between the different field sampling methods, sampling was performed at essentially 2-week intervals during the August-September, 1974, bloom period. An October (autumn) sampling was made at Lagoon Point, as well.

Water depths during the sampling times ranged from 2-5 meters, and the average depth within the Lagoon Point marina was 3 meters (10 feet, approximately). A 10-foot aluminium boat, which transported all the sampling gear, was used to reach the sampling stations. At each individual station and at each sampling time, samples were taken with a Van Dorn bottle at the depths listed in Appendix A.

The first sample was for dissolved oxygen using a 300 ml BOD bottle. The analysis method was the "Azide Modification of the Iodometric Method" described in Standard Methods (1).

Next, a 250-ml. sample was placed in a plastic bottle for nitrate (NO_3-N) analysis, with 1 ml. of a saturated solution of mercuric chloride added to preserve the sample. The sample was frozen until it was analyzed on a Technicon Autoanalyzer.

The next sample was placed in a 500 ml. plastic bottle for laboratory analysis for chlorophyll _a_, pH, and conductivity. Chlorophyll _a_ was analyzed using a Turner Model 110 fluorometer, following procedures given in (10). The pH was measured on a Beckman Zeromatic II pH meter, calibrated by using a standard solution. Conductivity was measured by use of a Labline Instruments Model MC-1 Lester Mho-Meter conductivity bridge.

The next sample was placed in a sterilized 50 ml. glass bottle for coliform analysis. The analyses, as prescribed in _Standard Methods_ (1), were the presumed and the confirmed tests, using dilutions of 10,1,0.1, and 0.01. The coliform analyses were run immediately upon return from the field sampling.

Water temperatures were measured using a mercury thermometer immersed in the sample bottle immediately upon withdrawal of water from the Van Dorn sampler.

V. EVALUATION OF WATER QUALITY - FLUSHING RESULTS

Lagoon Point Water Quality

This marina was sampled at seven points six times during August to October, 1974. In contrast to the other lagoons studied, this one shows a tendency to develop phytoplankton blooms and low D.O. content exceeding those in the nearby water body. Chlorophyll a (Chl a) reached a peak content of 25 μg/ℓ in September although sampling on a biweekly schedule may have missed occurring higher concentrations that were not observed. A dinoflaggelate ("red tide") bloom was observed in the lagoon on September 16, 1974. The patch at stations 1 and 2 remained rather generally distributed at slack tide and could be seen to break up as the tide flooded.

The mechanism allowing blooms such as those that develop in marinas would be a function of the residence time of water. The growth rate of phytoplankton in a marina would tend to be high because nutrient content would usually be non-limiting. As seen in Lagoon Point, NO_3-N is usually greater than 100 μg/ℓ although there were times when the concentration was reduced to about 10 μg/ℓ through phyloplankton utilization. The point is, adequate N is available to produce a bloom that turns the water red, or if it were diatoms, the water would be turned a golden brown at that Chl a content. Of course, NO_3-N will no doubt begin to limit growth rates when reduced to 10-50 μg/ℓ range, but for that to happen, the detention time of the marina water must be sufficiently long.

Following such blooms the plankton cells sink and begin to decompose and, or course, respire even if alive; however, the reduction of light caused by the increased cloudiness of the water results in reduced photosynthesis and oxygen production. Thus, at times following such blooms, the D.O. will reach relatively low levels. In Lagoon Point, several values recorded at the bottom ranged between 2 and 5 mg/ℓ D.O., a definite result of the preceeding blooms.

To illustrate the significance of detention time on bloom formation Fig. 9 shows the distribution of Chl a at the surface and at the bottom progressing from the entrance (sta 7) to the most distant inland point (sta 1) on September 13; that was the time of maximum observed bloom formation. These samples were collected from 9 to 10 a.m. on the 13th, during the period of a minus low tide. This probably explains the relatively high Chl a content near the outlet since the plankton cells sinking at the distant end of the marina would move toward the outlet as the water mass moved out during ebb tide. However, the patchiness observed (visually only) to result from flood tide breaking up the plankton bloom on September 16 suggests that a uniform distribution among the stations would not be expected. The point is that most of the biomass formation would be allowed in the most distant (closed) end, and least flushed part of the marina, and low D.O. and high Chl a observed in other parts of the marina.

Also shown on Fig. 9 is an approximate "detention time" for various sampling stations. The detention time, in days, is approximated by the expression

$$\text{Det. Time (days)} = \frac{1}{(1 - R_{hi}R_{lo})}$$

where two tides per day are assumed (vs. two tides per 24.8-hour lunar day) and the R_{hi} and R_{lo} are values for the large and small ranges respectively of the two semidiurnal tides in one lunar day as determined from the model flushing test data shown in Figs. 7 and 8.(R = 1 - E). The detention times shown in Fig. 9 are based on average values, as defined above, for the one-week period preceeding September 13. (See Chapter V

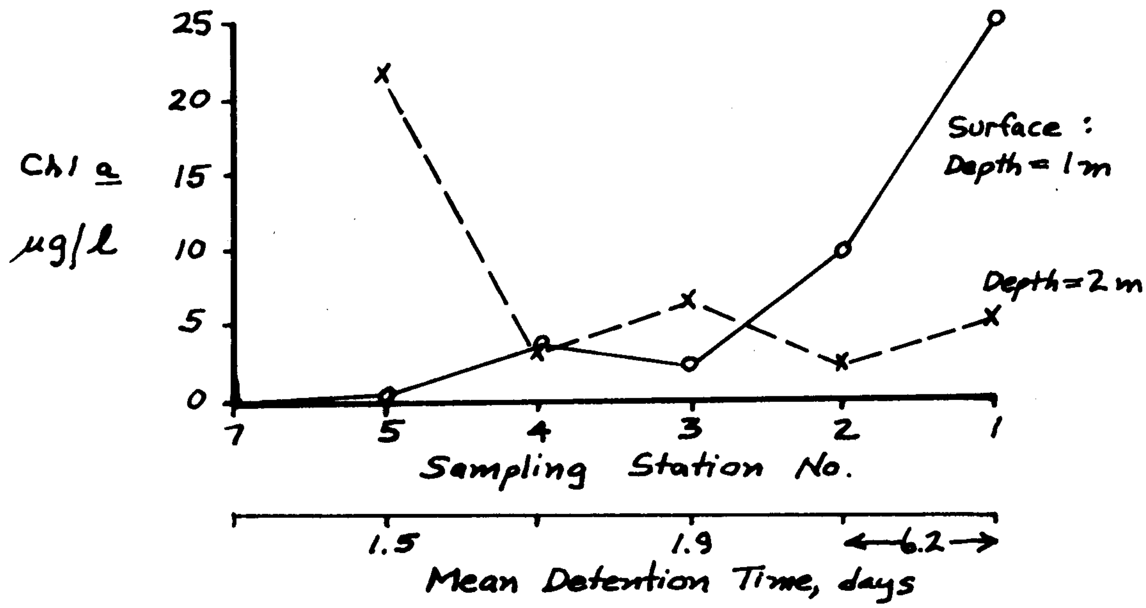

Figure 9 - Distribution of Chl a in Lagoon Point Marina, Related to Water Mean Residence Time, on September 13, 1974

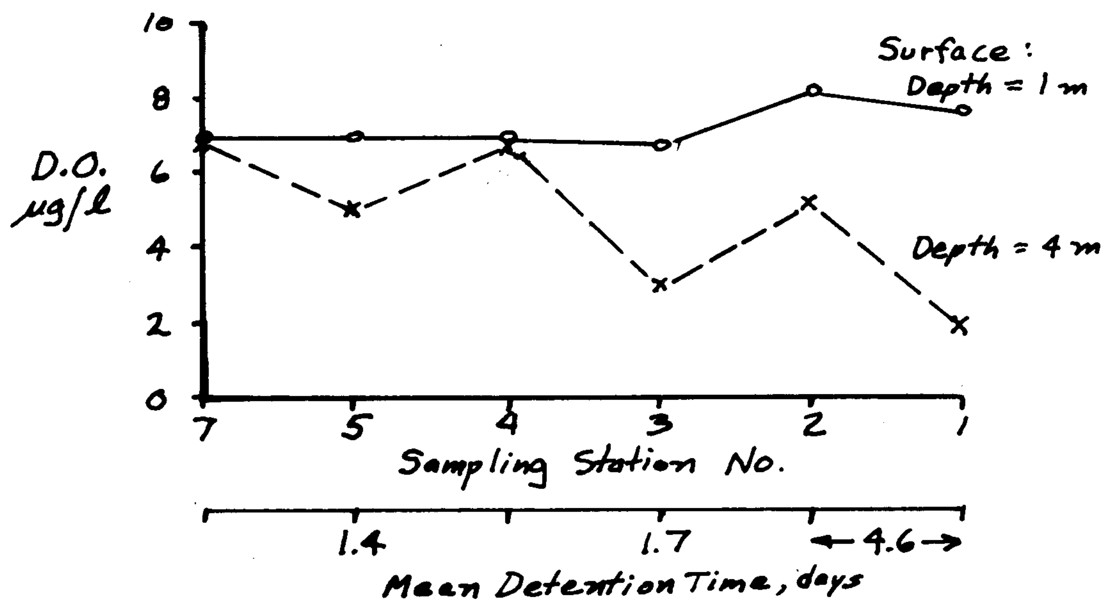

Figure 10 - Distribution of Dissolved Oxygen in Lagoon Point Marina on September 24, 1974, 11 Days Following a Phytoplankton Bloom

for the rationale of this choice. An approximation for a particular site would be $1 \div (1-R^2)$ where $R = 1 - E$ based on the average tide conditions.)

The minimum observed series of D.O. concentrations occurred on September 24, eleven days following the September 13 bloom. The September 24 sampling was done during a neap tide and, thus, a low flushing period. Although the distribution of D.O. does not show a uniform decline toward the least flushed closed end of the marina, nevertheless it seems clear that the trend of longer residence time of water there will on the average produce the lowest D.O. values. As residence time of the water increases the potential to realize larger plankton mass with resulting lower D.O., even to the point of anoxic conditions, also increases. The September 24 D.O. data are shown in Fig. 10. The "detention time" values shown are defined as above, with daily values based on tides occurring between September 13 and September 24.

Coliform organisms were detectable but at no time did values represent a problem. However, this marina is not used heavily and development of housing around the marina is still very sparse. With the low flushing rate in this marina, the problem of excessive coliform counts from boat activity as well as from septic tank drain fields are expected to occur. The lack of coliform buildup problems in Edmonds or Des Moines marinas is due no doubt to the adequate flushing rates, and also to "good housekeeping" rules limiting use of shipboard toilets in the marinas.

Biological Criteria for Marina Design

The Lagoon Point observations have provided conditions that are clearly undesirable from the standpoint of insufficient flushing action to prevent excessive plankton accumulation. Such conditions could potentially lead to anaerobic bottom water and even fish kills. However, the design of Edmonds and Des Moines marinas has allowed for enough flushing where such problems were not observed. In order to suggest criteria for flushing rates of marinas that are not apt to produce nuisance problems of excessive plankton accumulation and oxygen depletion, certain assumptions are necessary.

The assumptions are as follows: The maximum plankton crop assumed possible is 67 μg/ℓ Chl a, which is based on a maximum NO_3-N content in incoming sea water of about 300 μg/ℓ. If all that N were used by plankton then 67 μg/ℓ Chl a could theoretically result, applying typical ratios of 7.7:1 for C:N and 1 Chl a:30C. Further, growth rate (μ) would be assumed to be a maximum of 1.0 day^{-1} at 50% of incident light intensity. The effective mixing depth in the marinas is considered to be the total depth. Although at times there was as much as $1^{\circ}C$ difference between surface and bottom waters sampled, most of the time the plankton will be mixed to the bottom, thus, being exposed to an average light intensity present at one-half the depth of mixing, or total depth.

For purposes then of predicting the potential crop of plankton under different depths and dilution rates, the available light at the mid depths were estimated from

$$I_z = I_o e^{-Kz}$$

where I is light intensity, z is the midpoint of the mixing depth, and K is the extinction coefficient estimated from

$$K = \frac{1.7}{\text{Secchi disk reading}}$$

For this, a Secchi disk depth of 2.5m was chosen as a compromise value between 1.1 m, the value associated with 25 μg/ℓ Chl a and > 4 m, in which little particulate material existed in the marina. If the value of 1.1 were used to estimate the extinction coefficient then it was felt too much reliance would be placed on plankton self absorption of light to prevent a large bloom, whereas conservatively it is felt the emphasis should be placed upon dilution or flushing rate as the control.

Seven days was chosen as a reasonable growth period because of experience with the duration of plankton outbursts in Puget Sound and adjacent estuaries and also with the duration of the neap tide periods when minimum flushing by tidal action occurs. Therefore, as the marina depth increases the plankton growth rate would be expected to decline as the light available (one half mixing depth) decreased as a fraction of the intensity at 50% of full sunlight. The plankton crop after seven days and under a range of flushing rates and growth rates could be calculated from,

$$N_{7\ days} = N_o e^{(\mu - D) 7\ days}$$

where μ is the growth rate, D is the dilution or flushing rate (both in units of day^{-1}) and the initial N_o is 1 μg/ℓ Chl a. Again, assuming two tides per day, and using equal tides for first approximation, $D = 1 - R^2$. The auxiliary scale shows equivalent values of E, per cycle.

The predicted values for Chl a with dilution and mixing depth are shown in Fig. 11. The significance of mixing depth, or for practical considerations in marinas, total depth, is obvious. At all dilution rates D up to nearly 0.5/day there is a strong potential to approach the maximum biomass of plankton if the mixing depth is only 1 m.

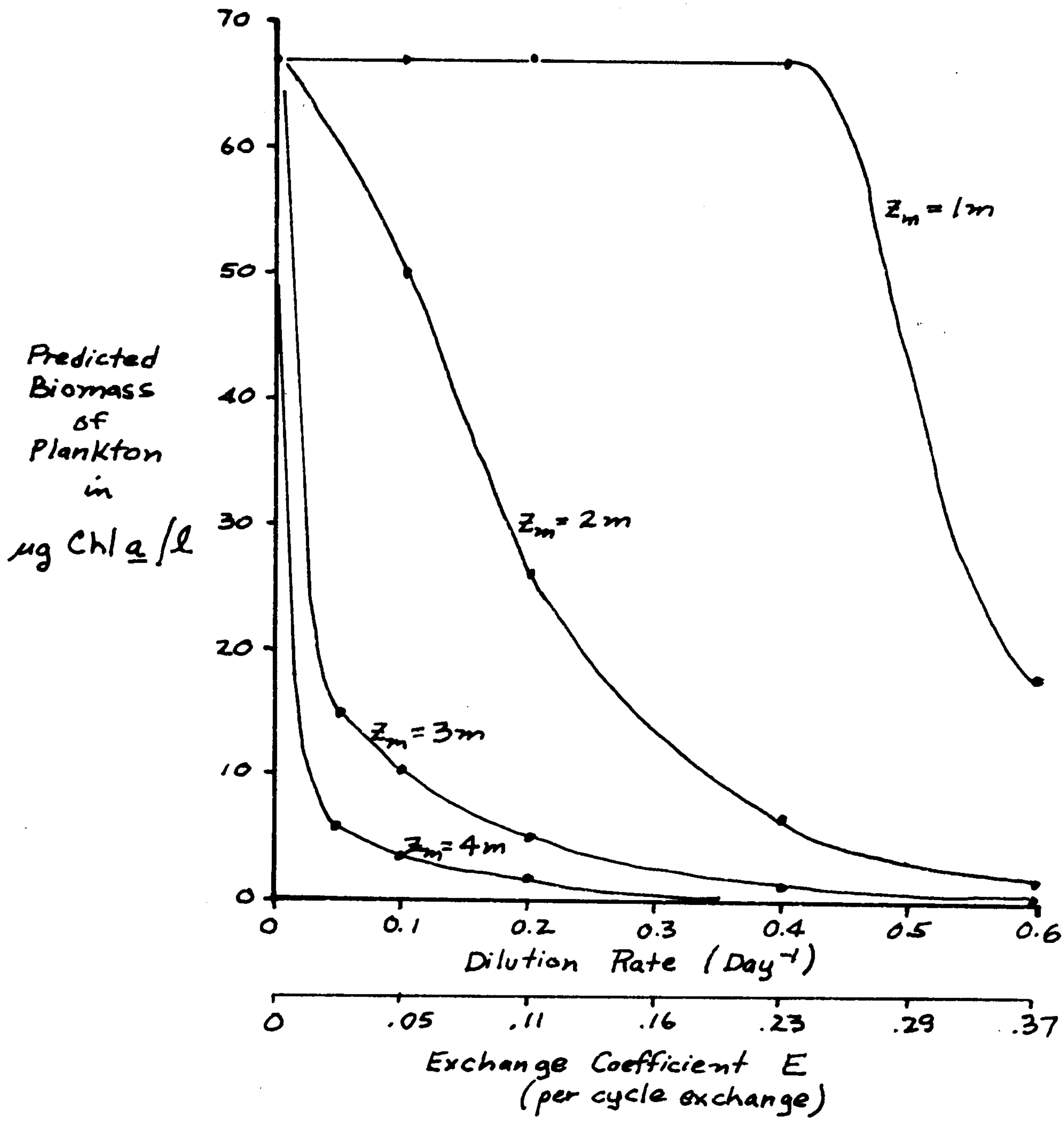

Figure 11 - Predicted Chl a Content Possible under Various Combinations of Dilution Rate and Mixing Depth in a 7-Day Period

However, with a depth of 2 m dilution has a more controlling influence. Thus, it would seem that marinas constructed with much less than 1 m depth below mean lower low water would result in a mean depth of around 2 m since the mean tide range is 2.3 m in Puget Sound. This means that the dilution or exchange rate must exceed 0.3/day if plankton blooms of the magnitude observed in Lagoon Point are to be avoided, as well as the associated low D.O. concentrations.

Lagoon Point depths sampled ranged from 1 to 4 m with a mean about 2.5 m. Thus, the 25 μg/ℓ Chl a observed in Lagoon Point would have been possible with dilution rates less than 0.2 /day and very likely one as low as 0.1/day was necessary. A dilution or exchange rate as low as or lower than 0.1/day was in fact predicted by the physical model for neap tide periods and for the closed end of the marina canal where the 25 μg/ℓ Chl a was observed. For 2.5 m depth and 0.1/day exchange rate, the plankton model here would predict 20 μg/ℓ Chl a.

Although the parameters used for these predicted biomass responses against dilution rate and mixing depth are hypothetical, they do provide rough criteria that should allow avoidance of problem conditions. There are other loss rates besides dilution that would tend to prevent large accumulations of biomass, such as grazing by animal plankton, natural death, and sinking. To deal in more detail with such predictions as presented here,without more data on these processes and realistic parameter values,seems unwarranted for the purpose at hand.

Such an approach as this has been used to explain the interaction of mixing depth and dilution rate on plankton blooms in the Duwamish estuary in Seattle. A mixing depth of 1 m, which is realistic during low river flow and the rather stable conditions promoted by neap tides, and a dilution rate of 0.13/day allows a plankton bloom to reach 70 μg/ℓ in 6.7 days. That biomass was actually reached in the estuary in 1966 in about 5 days (13), the maximum growth rate in that case was estimated from measured productivity/biomass ratios and was about 0.6/day. With a growth rate of 0.3/day with a 4-m mixing depth and an exchange rate estimated at 0.27/day for spring tide conditions and low river discharge, a bloom was impossible. Rather than implying great precision these predictions emphasize the significance of the physical factors in controlling the accumulation of plankton densities and the associated problem (14).

Comments on Salt Water vs. Fresh Water Marinas

Additional data presented in Appendix B were collected mostly under the grant reported in (6), but not incorporated in the report because they were collected too late to be incorporated in the formal report. They are presented here for completeness, and also to present some additional comments on the relative performance of salt water and fresh water marinas in the Puget Sound region.

Newport Shores Marina, on Lake Washington, has a canal-type layout (6); the dredged channels have water depths ranging from 9 to 12 feet. There is no inflow of fresh water to the marina other than run-off from the immediately adjacent residential area, largely concentrated in nine storm drains; water circulation is therefore minimal. The marina sections do not have any covered sheds; docks are adjacent to sewered homes.

The water in Edmonds Marina was always clearer than Lagoon Point; Secchi disk depths were usually 4-5 m, similar to open Puget Sounds. Newport Shores tended to be a little cloudier, probably because fresh water tends to have more colloidal material, but Chl *a* content did not exceed 5 μg/ℓ in the two marinas during the sampling period. This is typical of levels in the adjacent waters. Thus, no significant plankton buildup was observed in either marina. Further, D.O. did not deplete to low levels as it did in Lagoon Point. Coliform organisms, however, did reach higher levels, -1100 total coliform MPN/100 ml, in Newport Shores and 640 in Edmonds, respectively. These levels no doubt reflected the higher activity of boaters in Edmonds and Newport Shores. Future levels will also probably show increases over levels observed in Lagoon Point when it is completely developed. Considering the lower flushing rate buildups will no doubt be even higher.

Nitrate shows a strong depeltion in Newport Shores down to barely detectable levels while the depletion is not so great in Edmonds. This reflects the lower exchange and stronger stratification in Lake Washington than in Puget Sound, Breakdown in stratification frequently occurs in Puget Sound which results in high nutrient upwelled water reaching the surface. In Lake Washington, however, the water column stays permanently stratified from May to November. As a result NO_3 is depleted from the surface water which is the source of water to the Newport Shores marina. This then may account for the failure of sizable buildups of biomass in such a fresh water system. The potential for plankton and D.O. problems would seem to be considerably greater in salt water marinas in the Puget Sound region, if dilution is inadequate, than in fresh water, assuming no local sources of enrichment in fresh water marinas.

VI. CONCLUSIONS AND RECOMMENDATIONS

1. Marinas should probably be greater than two meters mean depth in the Puget Sound area in order to avoid visible abundances of plankton algae. If about two meters deep, algal problems (defined as chlorophyll _a_ concentration exceeding 25 μg/ℓ and subsequent lowered dissolved oxygen) can be avoided if the dilution rate exceeds 30% per day. If deeper, for example three meters, dilution rate could be as low as 10% per day and problems could be avoided.

2. These general criteria apply to individual segments in marinas rather than the average water exchange conditions in the whole marina. Long canal type marinas with a closed end should be avoided because they create segments with low water dilution or exchange rates. Even if relatively deep, a marina with a configuration that includes "dead pockets" or stagnant areas could also lead to a buildup of algal density, particularly if the vertical mixing was reduced from thermal stratification.

3. Because of an inadequacy of present mathematical models, the dilution rate (or exchange coefficient) determinations needed to estimate the acceptance of a given marina can most accurately be estimated with physical scale models.

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APPENDIX A-1

SAMPLING DATA, LAGOON POINT, AUGUST-OCTOBER, 1975

Column Headings:

Sta	:	Sampling station number
D	:	Depth below W.S., meters
Temp	:	Temperature, ^{o}C
DO	:	Dissolved oxygen, mg/ℓ
Cond	:	Conductivity, μ mhos x 10^4
NO_3-N	:	μg/ℓ
Chl a	:	μg/ℓ
TC	:	Total coliforms, no./100 mℓ
FC	:	Fecal coliforms, no./100 mℓ
SD	:	Secchi disk reading, m
% Sat	:	% Saturation, dissolved oxygen

LAGOON POINT 1 Aug. 1974

Sunny — Air Temp 23.5 ^{o}C — Wind 5 mph

Sta	D	Temp	pH	DO	Cond	NO_3-N	Chl a	TC	FC	SD	% Sat	Time
1	0.5	16	8.2	10.0	4.3	25.5	1.35	TNC		1.75	118	1030
	2	13.5	7.7	6.3	4.4	139	0.68	TNC			71	
2	0.5	15.5	8.2	10.2	4.2	62	1.35	TNC		2	119	1050
	2	14.0	7.8	7.8	4.3	125	4.56	184			89	
3	0.5	15.0	8.0	9.3	4.2	250	0.34	120		2	108	1105
	2	13.5	7.7	7.5	4.3	270	1.01	23			84	
4	0.5	15.5	8.5	9.1	4.2	125	0.42	94		1.5	106	1120
	1.5	14	8.3	7.8	4.2	116	0.30	46			87	
5	0.5	ther.	7.9	8.9	4.3	138	1.86	33		1.1	~104	1135
	1.5	broke	8.0	8.1	4.3	13	4.39	56			~ 92	
6	pipe		8.3	10.7	4.3	173	0.17	139		N/A	~124	1150
7	ent.		8.0	8.9	4.3		4.39	31		N/A	~100	1205

NOTE: Coliforms run by membrane filter method
TNC -- too numerous to count

LAGOON POINT 15 Aug. 1974

Sunny, Clear — Air Temp 21.5 ^{o}C — Wind 5 mph — Low Tide

Sta	D	Temp	pH	DO	Cond	NO_3-N	Chl a	TC	FC	SD	% Sat	Time
1	0.5	14.5	7.6	9.2	2.8	150	0.38	43	23	2.1	105	0935
	2	14.0	7.6	6.6	2.7	85.5	1.01	23	4		75	
2	0.5	14.5	7.7	9.1	2.65	202.5	0	4	4	2.2	105	0950
	2	14.0	7.8	8.2	2.7	off scale	0.57	4	0		93	
3	0.5	14.0	7.7	8.4	2.65	109	1.45	0	4	1.8	95	1005
	1.5	13.5	7.6	7.3	2.7	340	3.55	4	4		82	
4	0	15.0	7.7	8.3	2.7	103.5	0.76	9	9	1.0	97	1020
	1	14.5	7.7	7.7	2.7	90	0.19	0	0		89	
5	0.5	14.2	7.6	8.0	2.7	132.5	1.20	9	9	0.4	91	1030
	2	14.0	7.6	7.2	2.7	320.5	0.13	0	0		82	
6	pipe	16.2	7.8	9.6	2.7	37.5	0.32	4	4	N/A	113	1045
	mouth	14.1	7.8	8.9	2.75	200	1.58	4	4	N/A	101	1130

LAGOON POINT 15 Aug. 1974 (cont.)

NOTE: Sta 4 water depth 1.25 meters
Sta 5 construction work, water full of sediment

LAGOON POINT 30 Aug. 1974

Clear with some fog — Air Temp 19 °C

Sta	D	Temp	pH	DO	Cond	NO_3-N	Chl a	TC	FC	SD	% Sat	Time
1	1	16.5	8.1	10.9	3.2	42	1.52	9	0	2	130	1000
	3	15	7.6	6.6	3.1	11	1.86	15	15		77	
2	1	16.5	8.1	11.1	3.0	69	3.38	4	4	2.1	132	1015
	2	15.0	7.9	7.7	2.9	110	3.21	4	4		90	
3	1	15.5	8.0	10.4	2.9	33	1.35	23	23	2	122	1035
	2	14.5	7.8	6.8	3.0	22	6.92	9	9		78	
4	0	14.5	7.9	9.7	2.9	52	3.04	9	9	>1	111	1050
	1	14.75	7.8	9.1	2.8	52	1.69	9	9		106	
5	0	13.5	7.9	8.3	2.8	58	1.52	9	9	1.75	97	1100
	2	18.0	7.7	7.0	2.85	78	3.38	4	4		79	
6	pipe	12.75	8.3	11.2	2.85	48	0	23	23	N/A	137	
7	ent.		7.8	7.1	2.7	154	0.66	4	4	N/A	78	1130

NOTE: Sta 4, bottom depth 1.2 meters

LAGOON POINT 13 Sept 1974

Clear, no wind — Air Temp 16 °C

1	1	14.0	8.2	12.1	3.8	165	25.07	23	23	1.1	138	0910
	2	13.5	7.7	5.3	3.9	80	5.85	21	21		60	
2	1	14.0	8.0	10.2	4.0	80	10.02	0	0	1.6	116	0925
	2	13.8	7.8	7.9	3.9	57	2.36	0	0		89	
3	1	13.0	7.9	8.8	4.0	96	2.53	0	0	1.4	100	0945
	2	13.6	7.8	7.9	4.0	49	6.68	4	0		89	
4	0	14.0	7.8	8.7	3.9	95	3.55	43	43	>1.3	97	1000
	1	13.0	7.75	7.3	4.0	155	3.21	15	15		82	
5	0	16.1	7.7	7.9	4.0	88	0.07	15	7	0.9	90	1010
	2	14.0	7.7	5.0	4.0	171	21.72	23	23		56	
6	pipe		8.1	10.6	4.0	>>500	0.13	43	15		125	
7	ent.		7.85	7.5	4.0	276	0	0	0		85	1045

NOTE: Sta 1, water dirty, red, brown color
Sta 4, can see bottom

LAGOON POINT 24 Sept. 1974

Clear, no wind   Air Temp 20 °C   High Tide   Water Green, Gill Net Outside

Sta	D	Temp	pH	DO	Cond	NO_3-N	Chl *a*	TC	FC	SD	% Sat	Time
1	1	14.5	8.2	7.7	2.9	160	0.57			3	89	1010
	4	13.1	8.3	1.9	3.0	65	0.19				21	
2	1	14.0	8.3	8.1	2.9	240	3.96			3	92	1025
	4	13.2	8.3	5.2	3.0	90	1.95				58	
3	1	13.0	8.4	6.7	3.0	108	2.22			2.6	74	1040
	4	13.0	8.4	3.0	3.0	180	1.35				33	
4	1	13.1	8.5	7.0	3.0	380	0.50			4	78	1050
	3.5	13.0	8.5	7.0	3.0	125	0.63				78	
5	1	13.0	8.5	7.0	2.9	275	0.63			3.5	78	1100
	3.5	13.0	8.5	4.9	2.9	380	0.17				54	
6	Pipe Submerged by Tide											
7	0	13.0	8.5	7.0	3.0	116	0.32			>2	78	0940
	1.5	13.0	8.5	6.9	3.0	133	0.38				77	

NOTE: Sta 1: Green color, some surface plankton and flotsom
Sta 3: Green water
Sta 5: Bubbles when pulled up anchor H_2S??
Sta 7: Strong southerly currents on flood tide 30% outside. A Van Dorn bottle held out at 30-45°angle. can see bottom ~ 2 meters.

LAGOON POINT 10 Oct. 1974

Cloudy, Drizzle   Air Temp 18.5 °C   Wind 5 mph   Flood Tide

Sta	D	Temp	pH	DO	Cond	NO_3-N	Chl *a*	TC	FC	SD	% Sat	Time
1	1	11.4	6.4	7.0	4.0	210.2	8.96	0	0	2.1	75	0950
	4	11.7	6.6	5.8	4.0	280	2.05	4	0		63	
2	1	11.7	7.0	7.3	3.8	233.3	2.56	15	9	2.5	79	1010
	3.5	11.4	7.0	6.2	4.0	253.8	0.81	43	7		67	
3	1	11.4	7.1	6.9	4.0	274.7	1.64	0	0	>4	74	1025
	3	11.2	7.2	6.0	4.0	363.6	1.63	0	0		64	
4	1	11.4	7.3	7.1	3.7	315.6	2.03	0	0	>4	76	1035
	3	11.4	7.4	7.1	3.7	257.8	2.03	9	9		76	
5	0	11.4	7.6	7.4	3.7	267.4	1.52	0	0	>4	79	1050
	3.5	11.4	7.5	7.4	3.7	293.5	1.69	9	9		79	
6	pipe Submerged.											
7	ent.	11.4	7.7	7.4	3.7	276.5	2.03	43	15	N/A	79	1115

NOTE: Marina exceptionally clean and debris free

APPENDIX A-2

SAMPLING DATA, EDMONDS MARINA, JULY-SEPTEMBER 1974

EDMONDS 1500 10 July 1974

Cloudy Air Temp 17.0 °C Wind 20 kts

Sta	D	Temp	pH	DO	Cond	NO_3-N	Chl a	TC	FC	SD	% Sat	Time
1	1	14.5	7.7	10.0	2.65	45	0.32	43	240	4	115	1615
	2	14.0	7.8	9.9	2.62	45	0.19	240	240		113	
	3	13.5	7.8	9.5	2.65	55	0.63	43	23		107	
2	1	14.5	7.9	9.9	2.65	45	0.88	93	15	4.5	114	1630
	2	14.0	7.7	10.1	2,60	35	1.87	23	43		115	
	3	13.5	7.7	lost	2.65	70	1.51	240	240			
3	1	14.5	7.8	10.0	2.60	55	1.51	93	93	4.5	115	1525
	2	14.0	7.8	10.0	2.65	30	2.52	23	23		114	
	3	13.5	7.7	9.8	2.60	55	1.13	43	15		110	
4	1	14.0	7.7	9.5	2.62	32	1.13	23	9	4	108	1500
	2	13.5	7.8	9.5	2.65	38	1.51	460	460		107	
	3	13.0	7.8	9.3	2.75	120	0.82	240	240		103	
5	1	14.0	7.8	10.4	2.60	30	2.03	4	7	4.5	118	1545
	2	14.0	7.5	10.2	2.72	20	0.19	93	43		116	
	3	13.5	7.8	9.8	2.65	70	0.25	240	240		110	
6	1	13.5	7.9	9.7	2.65	60	1.01	240	240	4.0	109	1600
	2	13.0	7.8	9.3	2.65	90	2.63	210	210		103	
	4	12.5	7.7	9.1	2.75	160	1.07	93	43		100	

EDMONDS MARINA 1330 24 July 1974

Sunny, Clear Air Temp 25 °C No wind

1	1	16	7.8	10.1	2.4	177	0.41	4	0	>4	119	1500
	2	15	7.3	10.1	2.5	48.2	0.43	7	3		117	
	3	15	7.7	9.3	2.55	105	3.06	15	15		108	
2	1	15.2	7.8	10.1	2.5	100	0.43	4	4	>4	118	1515
	2	15.0	7.6	10.4	2.45	92.7	0.12	23	9		121	
	3	15.0	7.7	10.3	2.6	119.5	2.02	23	0		120	
3	1	15.5	7.7	10.2	2.45	112	0.86	43	7	>4	119	1420
	2	15.2	7.8	10.2	2.5	360	2.59	21	7		119	
	3	14.0	7.7	9.2	2.6	112		43	4		105	
4	1	15.2	7.8	10.1	2.5	272.4	0.05	9	4	>4	118	1400
	2	15.0	7.8	9.8	2.4	220	0.30	11	11		114	
	3	15.0	7.8	9.6	2.45	120	0.49	9	4		112	
5	1	16.0	7.6	10.5	2.45	359.5	0.62	23	4	>4	124	1435
	2	15.5	7.7	10.3	2.5	150	0.90	15	9		120	
	3	14.0	7.7	9.0	2.7	240	0.92	43	7		102	
6	1	14.5	7.7	9.7	2.6		0.33	93	21	8	111	1330
	2	14.5	7.7	10.0	2.55	130	0.43	240	240		115	
	4	13.0	7.7	8.8	2.7	198.6	0.36	11	7		98	

EDMONDS MARINA 7 Aug 1974

Sunny | Air Temp 25.5°C | Low Tide, Wind 5 mph

Sta	D	Temp	pH	DO	Cond	NO_3-N	Chl *a*	TC	FC	SD	% Sat	Time
1	3	16.5	8.4	11.9	3.8	690	5.40	7	7	>4	142	1545
	2	16.5	8.4	12.0	3.8	98	1.69	7	7		143	
	1	17.0	8.0	11.8	3.7	125	0.68	9	9		142	
2	2	17.0	8.4	11.8	3.7	118	2.28	15	15	>4	142	1600
	1	17.2	8.3	11.6	3.7	113.8	1.11	23	23		140	
3	3	16.5	8.6	11.4	3.8	20.0	2.45	23	9		136	
	2	17.0	8.3	11.1	3.7	350	2.03	43	43	>3.75	134	1500
	1	17.0	8.6	11.0	3.7	260	0.08	9	9		133	
4	3	17.0	8.3	11.2	3.8	230.8	3.04	23	23		135	
	2	17.0	8.5	11.2	3.75	15.0	0.43	43	43	>3.75	135	1445
	1	17.5	8.6	11.0	3.7	7.60	0.81	9	9		133	
5	3	16.5	8.5	11.4	3.8	436	1.86	39	39		136	
	2	17.0	8.5	11.4	3.7	64	0.62	20	20	>3.75	137	1515
	1	17.0	8.6	11.2	3.7	51	0.93	4	4		135	
6	4	16.0	8.6	11.3	3.8	510	3.89	4	4		133	
	2	16.5	8.5	11.5	3.8	61.5	1.86	0	0	3.5	137	1420
	1	17.0	8.6	11.5	3.8	14	0.30	4	4		135	

EDMONDS MARINA 23 Aug. 1975

Partly cloudy | Air Temp 26 °C | Wind 5 mph

1	1	14.5	7.7	7.2	3.00	250	0.25	93	93	>5	83	1545
	2	14.5	7.7	7.4	3.05	213.3	0.50	39	39		85	
	4	14.0	7.8	7.1	3.30	183.5	0.38	23	23		81	
2	1	15.2	8.5	8.0	3.10	197.2	0.25	93	93	>5	93	
	2	15	7.8	7.4	3.15	146	0.76	43	43		86	
	4	14	8.0	7.4	3.15	229.4	0.13	240	240		84	
3	1	15.5	7.7	7.4	3.20	206.4	0.69	93	43	>5	87	1520
	2	14.2	7.7	7.8	3.20	254.6	0.38	460	460		89	
	4	14.0	7.8	7.1	3.20	215.6	0.13	150	150		81	
4	1	16	7.7	7.5	3.20	225	0.50	7	7	>5	88	1500
	2	14.2	7.7	7.4	3.20	234	0.44	460	460		84	
	4	14.0	7.7	7.3	3.30	309.1	0.25	23	23		83	
5	1	15.5	7.8	7.4	3.20	403	0.63	43	43	>5	87	1530
	2	15	8.0	7.3	3.20	460	0.25	93	93		85	
	4	14	7.7	9.3	3.10	270	0.50	93	93		106	
6	1	15	7.8	7.6	3.20	275	0	23	23	4.5	88	1445
	2	14.2	7.7	7.7	3.00	138.6	.13	23	4		88	
	4	14	7.7	7.5	3.00	305.5	.063	93	11		88	

EDMONDS MARINA 6 Sept. 1974

Partly cloudy Air Temp 18 °C

Sta	D	Temp	pH	DO	Cond	NO_3-N	Chl *a*	TC	FC	SD	% Sat	Time
1	1	15.75	7.5	8.8	20	106	1.78	43	9	>5	103	1120
	2	14.25	7.5	8.8	20	70	0.43	93	93		100	
	4	13.75	7.5	8.3	20	156	0.25	64	23		94	
2	1	15.0	7.6	9.0	25	139	0.38	43	43	>5	105	1130
	2	15.0	7.6	8.7	25	106	0.50	23	23		101	
	4	14.25	7.6	8.3	25	287	0.13	43	15		95	
3	1	15.2	7.65	9.2	25	99	1.07	210	28	>5	107	1135
	2	15.0	7.7	9.0	25	75	0.19	43	43		105	
	4	14.5	7.7	7.9	25	345	0.38	9	9		91	
4	1	15.0	7.7	8.8	20	89	0.32	23	23	>5.5	102	1140
	2	15.0	7.7	8.9	20	220	0.25	23	23		103	
	4	14.25	7.7	8.0	20	187	0.35	43	43		91	
5	1	15.25	7.6	7.9	20	216	0.06	0	0	>5	92	1155
	2	14.25	7.6	8.2	20	119	0.57	23	23		94	
	4	14.0	7.65	8.0	20	500	0.06	64	64		91	
6	1	14.75	7.7	9.0	20	205	0.76	23	23	>6.5	104	1045
	3	14.5	7.8	8.9	20	300	0.13	23	23		102	
	5	14.0	7.7	9.1	30	250	0.82	43	43		103	

EDMONDS MARINA 23 Sept 1974

Clear Air Temp 18 °C Wind 5 mph

1	1	14	8.3	7.4	2.15	228	1.20			>5.5	84	1130
	2	14	8.3	7.0	2.15	205	1.51				80	
	4	13.5	8.4	7.3	2.15	75	1.58				82	
2	1	14	8.3	7.2	2.15	108	1.45			>5.5	82	1140
	2	14	8.2	7.1	2.15	144	1.58				81	
	4	13.8	8.2	7.4	2.15	300	1.89				84	
3	1	13.8	8.2	7.3	2.15	1000	1.58			6	83	1045
	2	13.5	8.2	7.1	2.15	195	1.26				80	
	4	13.2	8.2	7.0	2.15	59	1.32				77	
4	1	13.8	8.0	9.0	2.15	185	0.95			>5.5	102	1020
	2	13.5	8.0	7.1	2.15	940	1.26				80	
	4	13.5	8.2	7.1	2.15	145	1.45				80	
5	1	13.5	7.6	7.0	2.15	2000	0.88			>5.5	79	1100
	2	13.5	7.8	7.0	2.15	260	0.06				79	
	4	13.5	7.5	6.8	2.15	720	1.26				76	
6	1	13.0	6.4	7.6	2.15	1540	1.32			5.5	85	1000
	2	13.0	6.8	7.3	2.15	200	0.06				81	
	4	13.0	7.1	7.3	2.15	230	0.50				81	

APPENDIX B-1

SAMPLING DATA, EDMONDS MARINA, APRIL-JUNE 1974

EDMONDS MARINA Begin 1330 26 April 1974

Cloudy, Drizzle

Sta	D	Temp	pH	DO	NO_3-N	Chl *a*	TC	FC	SD	% Sat
1	2.5	10.0	7.8	9.3	232				3.5	97
	1.0	10.1	8.0	13.0	126				clear	136
	0.5	9.8	8.0	13.0	51					135
	2.5	9.5	7.8	11.0	128				4.0	113
	1.0	9.9	7.9	12.3	95				clear	128
	0.5	10.0	7.9	12.8	89					133
3	2.5	9.5	7.8	10.5	220				3.5	108
	1.0	9.9	8.0	13.7	107				clear	143
	0.5	9.8	8.1	12.8	52					132
4	2.5	9.2	8.1	11.5	90				3.0	118
	1.0	9.7	8.2	11.5	89				clear	119
	0.5	9.8	8.3	12.8	91					132
5	2.0	9.8	8.2	13.2	213				3.0	137
	1.0	10.0	8.1	12.7	83				clear	132
	0.5	10.1	8.1	12.2	117					127
6	4.0	9.5	8.1	12.4	87				3.0	127
	2.0	9.8	8.2	12.7	112					132
	1.0	9.9	--	13.2	90					137

EDMONDS MARINA Begin 1245 10 May 1974

Sunny

1	2.0	11.3	7.9	9.8	233				clear	104
	1.0	12.3	8.0	9.9	22					108
	0.5	12.3	8.0	9.4	62					102
2	2.0	11.8	7.9	9.7	238				clear	105
	1.0	11.5	7.8	9.7	131					104
	0.5	11.8	7.8	9.7	223					104
3	2.0	11.3	7.9	9.4	206				clear	101
	1.0	11.3	8.0	9.5	194					102
	0.5	12.0	8.0	9.4	200					102
4	2.0	11.0	8.0	9.6	233				clear	102
	1.0	11.5	8.0	9.5	117					102
	0.5	12.0	8.0	9.5	222					103
5	2.0	11.5	7.9	9.7	141				clear	104
	1.0	11.5	7.9	9.7	182					104
	0.5	11.5	7.9	9.7	210					104
6	4.0	10.8	8.0	9.7	245				6.5	110
	2.0	10.8	8.0	9.2	247					111
	1.0	10.8	8.0	9.9	202					111

EDMONDS MARINA Begin 1330 24 May 1974

Overcast - Rain Wind 25 Knots

Sta	D	Temp	pH	DO	NO_3-N	Chl *a*	TC	FC	SD	% Sat
1	0.5	11.5	8.2	12.4	65	9.4		3	2.5	133
	1.0	12.5	8.2	12.4	63	8.1		0		136
	2.0	12.0	8.1	11.6	95	20.8		4		126
2	0.5	12.0	8.1	12.1	103	3.7		0	2.5	131
	1.0	12.0	8.1	12.3	55	3.2		4		134
	2.0	11.5	8.6	11.8	118	3.8		4		127
3	0.5	12.0	3.2	11.6	53	1.6		4	2.8	126
	1.0	11.5	8.1	11.3	113	4.2		4		126
	2.0	11.5	8.9	11.4	112	2.6		0		122
4	0.5	13.0	8.2	11.2	47	2.8		0	2.5	124
	1.0	12.0	8.1	11.6	75	2.0		3		126
	2.0	11.5	8.0	11.4	114	3.3		3		123
5	0.5	12.0	8.1	11.7	90	2.2		3	2.5	128
	1.0	11.5	8.1	11.4	121	4.3		4		123
	2.0	11.5	8.1	11.4	102	3.0		3		122
6	1.0	11.5	8.1	11.0	128	4.3		0		114
	2.0	11.0	8.1	10.7	97	4.8		9		114
	4.0	10.5	7.9	9.7	204	3.3		4		109

EDMONDS MARINA Begin 1300 12 June 1974

Sunny

Sta	D	Temp	pH	DO	NO_3-N	Chl *a*	TC	FC	SD	% Sat
1	0.5	16.3	8.2	9.3	35	0.3	93	3	5.0	110
	1.0	16.0	8.2	9.2	155	0.9	43	23		109
	2.0	15.0	8.2	9.1	165	0.9	43	15		106
2	1	15.0	8.2	9.3	45	0.6	43	43	5.0	106
	2	14.0	8.2	9.2	185	0.6	240	240		105
	4.5	13.8	8.1	8.8	150	0.1	150	28		99
3	1	14.5	8.2	9.3	340	0.3	43	15	5.5	106
	2	14.3	8.1	9.1	90	0.4	240	43		104
	4	13.5	8.1	9.0	110	0.2	39	39		102
4	1	14.5	8.1	9.1	70	1.5	23	9	4.5	104
	2	13.3	8.1	9.1	150	0.4	240	21		102
	4	13.0	8.1	9.0	45	1.1	<3	<3		99
5	1	14.5	8.1	9.0	135	0.6	9	9	4.5	104
	2	13.8	8.1	9.1	55	0.2	93	93		102
	4	13.5	8.1	9.2	40	0.6	45	45		104
6	2	14.0	8.0	9.6	50	0.2	<3	<3	4.0	109
	4	14.0	8.1	9.3	185	0.4	43	15		106
	6	13.3	8.1	8.6	190	0.7	3	43		97

EDMONDS MARINA   Begin 1130   27 June 1974

Partly cloudy - Sound Choppy

Sta	D	Temp	pH	DO	NO_3-N	Chl a	TC	FC	SD	% Sat
1	1	13.3	7.9	8.6	120	2.4	7	11	5.5	96
	2	13.0	7.9	8.5	140	1.4	240	11		94
	3	13.0	8.3	8.5	55	2.8	1100	-		94
2	1	14.5	7.9	8.6	65	3.7	93	3	5.5	105
	2	14.0	7.9	8.4	95	2.6	>2400	156		95
	3	14.0	7.9	8.5	145	1.9		-		96
3	1	15.0	7.9	8.1	105	1.4	43	<3	4.0	102
	2	14.0	7.9	8.7	60	3.2	93	9		99
	3	14.0	7.9	8.6	110	2.3	240	4		97
4	1	14.0	8.0	8.7	110	2.7	43	-	5.0	98
	2	14.0	8.0	8.7	65	2.7	43	4		99
	3	14.0	8.0	8.7	140	2.5	460	-		98
5	1	14.0	7.9	8.3	120	3.3	240	<3	4.5	94
	2	14.0	7.9	8.5	120	3.4	93	<3		97
	3	14.0	7.9	8.4	75	3.2	460	4		95
6	2	14.0	8.0	8.6	150	1.8	23	23		98
	4	13.0	7.9	8.3	55	--	43	-		93

APPENDIX B-2

SAMPLING DATA, NEWPORT SHORES MARINA, MAY-JULY 1974

NEWPORT SHORES MARINA Begin 1200 3 May 1974

Sunny

Sta	D	Temp	pH	DO	NO_3-N	Chl *a*	TC	FC	SD	% Sat
1	2.0	12.7	7.5	12.1	118				2.0	113
	1.0	13.9	7.5	11.7	108					113
	0.5	14.5	7.6	12.5	109					123
2	2.0	13.0	7.6	12.0	157				2.0	113
	1.0	13.3	7.6	12.0	158					113
	0.5	14.0	7.6	11.8	152					114
3	2.0	12.9	7.6	12.0	196				2.5	113
	1.0	13.0	7.6	11.8	192					111
	0.5	13.1	7.5	11.8	197					111
4	4.0	11.9	7.7	12.1	204				4.0	112
	2.5	12.1	7.7	12.2	211					113
	1.0	12.3	7.6	12.1	205					113
5	2.0	13.3	7.5	11.8	112				2.5	111
	1.0	13.3	7.8	12.0	115					114
	0.5	13.8	7.6	12.0	114					104

NEWPORT SHORES MARINA Begin 1230 17 May 1974

Windy, overcast

Sta	D	Temp	pH	DO	NO_3-N	Chl *a*	TC	FC	SD	% Sat
1	0.5	13.8	8.2	12.5	117				1.5	120
	1.0	13.9	8.3	12.6	55					121
	2.0	12.8	8.0	12.8	116					120
2	0.5	13.0	8.3	12.2	98				2.0	116
	1.0	12.5	8.2	12.5	68					117
	2.0	12.1	8.0	12.4	146					115
3	0.5	13.5	8.1	12.6	128				2.0	120
	1.0	12.5	8.2	12.6	72					118
	2.0	12.5	8.1	12.5	111					116
4	1.0	12.0	8.2	12.4	188				2.5	115
	2.5	11.5	8.1	12.2	123					112
	4.0	12.0	7.4	12.0	114					111
5	0.5	14.5	8.0	12.4	61				2.0	121
	1.0	14.3	7.8	12.7	49					122
	2.0	14.0	7.8	12.4	66					119

NEWPORT SHORES MARINA Begin 1330 14 June 1974

Cloudy

Sta	D	Temp	pH	DO	NO_3-N	Chl *a*	TC	FC	SD	% Sat
1	0.5	19.0	8.4	11.5	20		<3	<3		122
	1.0	19.0	8.8	11.1	30		15	15		118
	2.0	18.0	8.4	11.3	35		21	15		119
2	0.5	19.0	8.4	11.0	50		4	4		117
	1.0	19.0	8.4	11.1	35		7	7		118
	2.0	18.0	8.1	11.2	35		3	3		117
3	0.5	18.5	8.2	10.8	35		-	21		114
	1.0	18.5	8.4	10.8	40		21	11		114
	2.0	18.5	8.5	10.9	70		23	9		115
4	1.0	18.0	7.8	11.0	60		-	-		116
	2.0	17.5	8.2	11.3	65		-	-		117
	4.0	17.5	9.2	10.9	65		-	-		113
5	0.5	18.8	8.5	11.8	30		7	7		124
	1.0	19.0	8.4	11.3	25		15	4		120
	2.0	18.0	8.4	11.6	30		3	3		122

NEWPORT SHORES MARINA Begin 1030 4 July 1974 Air Temp 22°C

Cloudy

Sta	D	Temp	pH	DO	NO_3-N	Chl *a*	TC	FC	SD	% Sat
1	0.5	20.0	7.3	9.1	5	4.15	120	11	1.5	115
	1.0	20.0	7.5	9.2	5	1.69	23	23		116
	2.0	19.5	7.4	9.1	5	0.76	11	21		114
2	0.5	19.5	7.8	9.2	5	1.10	11	11	1.5	116
	1.0	19.5	7.3	9.3	5	4.30	43	43		117
	2.0	19.0	7.3	9.2	5	2.24	9	9		115
3	0.5	19.5	7.4	9.6	5	2.87	11000	11000	1.5	121
	1.0	19.5	7.7	9.6	5	1.35	1100	1100		121
	2.0	19.5	7.3	9.5	5	4.89	23	23		119
4	1.0	19.0	7.7	10.0	5	3.88	4	4	1.8	125
	2.0	19.5	7.9	9.9	5	3.55	23	9		125
	4.0	19.5	7.7	9.8	5	2.36	4	4		123
5	0.5	20.0	7.3	9.4	5	2.87	23	9	1.5	119
	1.0	20.0	7.3	9.4	5	4.56	23	23		119
	2.0	19.5	7.0	9.3	5	2.70	23	9		117

NEWPORT SHORES MARINA   Begin 1500   17 July 1974

Raining - no wind   Air Temp 23°C

Sta	D	Temp	pH	DO	NO_3-N	Chl *a*	TC	FC	SD	% Sat
1	0.5	20.0	7.7	8.3	25	2.7	1500	1100	1.0	105
	1.0	19.5	7.4	8.6	210	1.6	240	240		108
	2.0	19.0	7.6	8.8	20	2.4	460	460		110
2	0.5	20.1	7.9	9.8	20	0.7	150	150	2.0	124
	1.0	20.1	7.9	9.8	7	0.9	460	460		124
	2.0	20.0	7.6	9.8	7500	10.0	43	43		123
3	0.5	20.0	8.3	9.6	60	1.2	460	460	1.5	122
	1.0	20.0	7.7	9.7	10	0.4	1100	1100		123
	2.0	20.0	8.0	9.9	40	0.3	460	460		125
4	1.0	19.2	8.9	10.4	15	0.2	43	43	2.0	130
	2.0	19.2	9.6	10.4	2	0.1	43	43		130
	4.0	19.2	8.3	9.9	80	1.1	150	150		124
5	0.5	20.0	8.1	9.1	20	3.9	460	460	1.5	115
	1.0	20.0	7.8	8.8	15	3.5	1100	1100		111
	2.0	20.2	7.2	8.8	25	4.8	240	240		111