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Report to Bureau of Sport Fisheries and
Wildlife, Fish and Wildlife Service

EFFECTS OF RIVER FLOW REGULATION BY SALEM CHURCH DAM ON MARINE ORGANISMS

by

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Introduction

Salem Church Dam, which is being proposed for the Rappahannock River, seems certain to create changes in distribution, abundance and ecological relationships of marine organisms in the estuary. Storage of water in the reservoir and operating requirements of the dam would moderate extreme low salinities in the spring and extreme high salinities in summer and fall. Winter and spring are the seasons of high riverflow when water would be stored, and summer and fall are periods when releases above normal riverflow would often be needed to maintain water quality by abating pollution.

This report is concerned primarily with the effects on oysters and some of their associates of hydrographic changes that would be caused by the dam. Other marine organisms are certain to be affected in ways only vaguely preceived at present. The distribution and activity of oyster drills and certain diseases of oysters, such as those caused by MSX and *Dermocystidium*, are regulated annually or at intervals of several years by low spring salinities and high summer and fall salinities. It is probable that moderation of extremes, particularly of spring salinities, would permit predators, diseases and other pests of oysters to penetrate farther up river into now productive oyster-growing areas. The changes would also permit increased abundance and activity in the areas now infested. It is a striking feature of the Rappahannock River that success of oyster culture on public and private grounds changes abruptly at about mile 15 where most of these pests cease to occur.

A preliminary report by the Bureau of Sport Fisheries and Wildlife, to the Corps of Engineers at Norfolk, Virginia, dated 7 September 1962, gives a general account of hydrographic and biological problems involved. Certain refinements and changes in requirements will be noted in the present report as a result of conferences and additional studies by Virginia Institute of Marine Science, the U. S. Fish and Wildlife Service, and Norfolk Corps of Engineer personnel. It is presumed that the Sport Fisheries and Wildlife Bureau, as well as any other agency having access to this report, has available the list of supplementary exhibits in the addenda as well as the cited references. It should also be noted that the Corps of Engineers now has three plans of operation for Salem Church Dam--one of which does not involve production of electric power. This has led to new concepts of the use of stored water for biological purposes.

A program has gradually evolved at the Virginia Institute of Marine Science which provides for regulated water releases in two seasons and for two purposes. First, <u>mitigation</u> of drill damage by planned releases in the <u>spring</u> of the wettest years--those which fall in the upper one-third when ranked by total run-off from October through May. Second, <u>benefits</u> by planned releases in <u>summer</u> (July through September) in those remaining years in which the reservoir is filled by 1 May. It is evident that mitigation and benefit releases cannot be obtained in the same year. This report assesses the hydrographic requirements for biological control and is concerned primarily with predictions of river-flow needed to effect these requirements in terms of salinity.

MITIGATION RELEASES

Biological Considerations

Plans for spring releases are based primarily upon the requirements necessary to keep oyster drills in their present status in the Rappahannock River. The "drill line" or upper limit of drill populations in the Rappahannock has been observed regularly in annual surveys by Institute personnel for many years. This area is just above Towles Point opposite Urbanna, Virginia, at mile 15 in the river. This up river limit was confirmed in separate studies by the Bureau of Commercial Fisheries in the relatively wet years of 1960 and 1961 (Griffith and Engle, Mimeo Report)

Some drills may be killed each spring by freshets, but it is believed that their distribution is largely regulated by low spring salinities in irregularly occurring wet years. Accordingly, as a basis for calculations for mitigation releases, it is assumed that only the wettest years are effective in drill control. It is also likely that by proper manipulation there will be adequate water in some wet years to push the drill line farther down river thereby producing benefits to oysters.

Laboratory studies by Langley Wood and data from James B. Engle have been used as a basis for estimating the levels and durations of low salinities required to kill drills. The values chosen are a salinity of 10‰ for 20 days when temperatures have reached 20°C. These conditions must be produced at a depth of 15 feet, which includes most oyster beds, although deeper saltier sanctuary-areas exist. Extracts of Wood's experimental data supporting these determinations are given in Table I.

Hydrographic Considerations

1. Computation problems and data deficiencies

To determine if the physical requirements for killing drills can be obtained by manipulation of water flow from the reservoir, it is necessary to convert river flows into salinity values at various points and depths in the estuary. This is difficult because field data are inadequate and methods of computation are not well established. An appreciation of the difficulties involved can be obtained from D. W. Pritchard's (1959) report which predicts the effects of increased summer flows on salinities in Delaware Bay. Storage of winter and spring run-off in reservoirs would provide the necessary fresh water. It is interesting to note that Dr. Pritchard required steady-state conditions of riverflow and salinity distribution. Since this is seldom approached in a natural estuary, he obtained his data from the controlled Delaware model at Vicksburg. Also, only longitudinal variations in salinity, that is, a one-dimensional system was considered. Knowledge of eddy diffusivity is not sufficiently advanced to calculate salinities in a three-dimensional system. Furthermore, an unknown inflow of groundwater from areas below the dam may be of importance and the contributions of downstream tributaries vary with season. These points are brought out to emphasize the difficulty encountered in translating riverflows into salinities in the Rappahannock estuary. There is no model of the Rappahannock River. Furthermore, our salinity data for winter-spring periods are quite limited.

It has been necessary to use empirical methods of estimating the relationship between river flows and salinities. Lag-times between river-flows and resulting salinities vary with riverflow, size and morphometry of the estuary and other factors. For example Beaven (1946) compared Susquehanna River flow with Chesapeake Bay salinities and concluded that a six-month progressive average daily flow gave the best agreement with observed salinities. Pritchard (1955) and Nichols (1963) estimate much shorter lag periods for the smaller Rappahannock system--of the order of 7 to 21 days--depending upon rate of river discharge. This has led to questions as to what seasons should be used in correlating riverflows and salinities--spring only or all year around. Also, what is a reliable basis for calculating the vertical stratification during these spring periods of high run-off? Vertical stratification tends to become stronger with increased fresh-water flow up to a point, at which it breaks down and the river becomes fresh from top to bottom. However, this breakdown of stratification has never been observed and is not believed to occur in the Urbanna-Morattico area of concern here.

Another problem is to determine the effect of the salinity regime prevailing in Chesapeake Bay off the mouth of the river which provides the "sump" or source of saltwater. It is believed that winter and spring weather conditions are so wide-spread geographically that a wet year in the Susquehanna drainage system would also be a wet year in the Rappahannock system. But the salinity regime off the mouth of the river may not follow local run-off conditions in summer and fall. Summer rainfall patterns are much more erratic and localized. The level of salinity in this Rappahannock "sump" varies from year to year and season to season--far more in fact than the ocean varies off the mouth of Delaware Bay.

2. Estimates by oceanographers

Calculations of riverflows required to produce salinities of

10‰ for 20 days at a depth of 15 feet at the level of Urbanna have been made by Dr. Maynard Nichols, Oceanographer at the Virginia Institute of Marine Science. His estimates are based upon riverflows and salinities at all seasons of the year. Figure 2 (from Nichols 1963) shows wide variations in the relation between observed riverflows and observed salinities. This is to be expected in a river with large seasonal variations in both factors. A vertical salinity gradient of 1.5‰ between surface and 15 feet was predicted. This means that to obtain a salinity of 10‰ at 15 feet, the approximate maximum depth of most oyster beds in the area, requires a salinity of 8.5‰ at the surface. According to Nichols' calculations, a flow of 6500 cfs would be required to produce the salinities desired at Urbanna. The Corps of Engineers rule curves on Salem Church Dam show that this amount of water can be released in 13 out of 18 wettest years of record without serious drawdown--that is, drawdowns not exceeding 10 feet. This would be a mitigation release hence neither a benefit nor a charge against the reservoir or its power pool would result.

For comparison and evaluation of Nichols' estimate one may examine Pritchard's work on the Rappahannock. A study of Pritchard's curves for surface salinities and river flows in the Rappahannock River (Pritchard 1955, Fig. 6, copy attached), based on data from all seasons, indicates that 5400 cfs would be required at mile 15 (Urbanna) to produce a salinity of 8.5 ppt

3. <u>An empirical check of required riverflow for mitigation</u>

The <u>only</u> wet year of record for which we have adequate spring salinity data is 1958 (Table 2). This year ranked 14th in 18 wet years, hence, is closer to average in riverflow than most wet years. This is good for the present purposes, because field data indicate that 1958 was an effective year in reducing the range and the abundance of drills. For 1958, spring salinity records are available for three dates immediately before, during and after the optimum time (1 May usually) of projected mitigation releases. One very complete salinity profile at frequent depths on 4 May and two others in April and June are shown in Figs. 3a, 3b, and 3c. The salinity regimes shown were produced by a rather steady flow of about 3000 cfs all winter and spring. In other words, an approximation of a steady state in Nature with a fresh-water release of 3000 cfs produced almost exactly the salinities necessary to kill drills on oyster beds at Urbanna. Pritchard believes that a continuous flow of 3000 cfs will reach equilibrium within 20 days, that is, produce the lowest steady salinities possible with that amount of release. However, if water is being stored in Salem Church Reservoir all winter and spring, the river would probably be saltier than usual when the manipulated release is initiated. Furthermore, 20 days of 10‰ salinity would be required after steady state had been reached. Hence, it is obvious that a 3000 cfs release for 20 days would not produce the necessary conditions to kill drills.

The runoff immediately prior to the winter of 1957-58 was about average, hence it appears that most "wet" years are probably effective in killing drills under natural conditions. It follows that wet years and possibly some "average" years can be manipulated to satisfy mitigation purposes because much less water is used in short-term high-flow releases than the total runoff for the October to May storage period. Such average-year mitigation releases would depend upon taking advantage of occasional depressions of salinity levels in the river and particularly in the "sump" from short-term excessive runoffs in April and May.

4. Conclusions on riverflow required

In summary, detailed examination of a moderately wet year indicates that a 20-day release at discharge rates well above 3000 cfs will be required. It must be remembered that reducing salinity level becomes disproportionately difficult as riverflow increases. Nichols has estimated that 6500 cfs will be required to provide necessary salinities for drill mitigation in 20 days. Pritchard, in an estimate based on 1958 conditions, thinks 6000 cfs is a reasonable figure. Hence a planned release of 6500 cfs for 20 days in certain wet years should be provided for mitigation purposes. Several reasons can be cited for this recommendation. The choice of 10‰ salinity as a physiological base line is a little optimistic since almost no drills died at 11.4‰. The vertical stratification of salinity under high-flow conditions is critical but poorly documented. If the difference in salinity between surface and 15 foot depth should exceed 1.5‰, much more water would be required than the 3000 cfs in 1958 from which this gradient was obtained. The dynamics of exchange of water between the Chesapeake "sump" and the river when nearly all water is being stored from October to May remain unexplored in the absence of a model. An inversion of salt gradient might develop in which the river was saltier than the Bay--which would be receiving normal runoff. Such dynamics can be studied in a model--or in the river after the dam is built.

In short, several scientists approaching the problem from different viewpoints have arrived at similar estimates of the required runoff. A release of 6500 cfs for 20 days about 1 May when temperatures have reached 20°C is about the minimal requirement which seems adequate to protect the oyster industry. Once fixed in the operating plans, the amount of water released can be reduced if less is found to be adequate but an increase is not likely. Higher flows for shorter periods are possible but dangerous to oysters and other organisms. Lower flows for longer periods may be effective but will take a disproportionate amount of water. Since a release of 6500 cfs would not cause excessive drawdowns in most wet years, this figure does not seem unreasonable.

SUMMER-FALL RELEASES FOR BENEFITS TO OYSTERS

During earlier discussions of the VIMS Salem Church Dam Committee with the office of the District Engineer, it developed that benefits to oyster culture in the Rappahannock might accrue if it were possible to manipulate flows to decrease summer salinities. A discussion of this possibility follows.

A study of riverflow records covering the last 54 years indicates that after the 18 wet years have been allocated for mitigation releases, over half the remaining years had sufficient riverflow to provide summer releases for benefits. In addition spring mitigation releases may not be needed in successive wet years hence some wet years could be used for benefit releases in summer. The initial criteria postulated for calculation of rule curves by the Corps of Engineers were that if the dam was full on 1 May, water was to be released at a daily rate between 2500 and 3500 cfs during the month of July, August, and September. As much water as possible was to be stored and released, provided it did not interfere seriously with the power pool. The Corps of Engineers calculated a rule curve on this basis and found that 2200 cfs on the average could be released but decided that excessive drawdown in most years would create problems in recreational and fish and game areas.

A study of the effects on summer salinities of releasing some 2500 to 3500 cfs of stored water has opened new vistas on the possibility of benefits from summer releases. Summer changes in salinity are likely to be much more drastic per unit of discharge than was first believed.

Ignoring high evaporation and reduced runoff in summer, for the moment, it is much easier to modify salinities at low-flow conditions than at high ones. Since flows are already low in summer, a given release of fresh-water from the reservoir above natural flow would reduce salinities more in summer than in winter. It must be remembered, however, that the "sump" will contain much higher-salinity source water in the summer.

Pritchard's studies (1959, Fig. 23) in the Delaware Bay and his graphs of Rappahannock River flow-salinity relationships (1955, copy enclosed) suggest that the amount of water available for storage in these systems is sufficient to cause rather drastic salinity changes in summer. In Delaware Bay his most drastic regulated flow produced maximum summer changes of 7‰. Pritchard's graph for the Rappahannock River (Fig. 6 of 1955 paper, copy enclosed) suggests changes of about 4‰ for 1000 cfs of added flow, 6‰ for 2000 cfs and 7‰ for 3000 cfs at the Urbanna (mile 15) level of the river. These salinity reductions are much greater per unit of released riverflow than we had anticipated. As Pritchard's Fig. 23 shows, the changes would be greatly attenuated at both ends of the estuary and most drastic in the middle.

It now appears that in average years an additional release of 1000 cfs above natural flow would produce as much salinity change as biologists would wish to experiment with at present. A change of 4‰ might cause rather major effects. It is possible that oyster drills could be eliminated from the river. Combinations of summer releases to deny drills suitable breeding habitat and spring releases to purge adult populations could conceivably be manipulated to exterminate drills in the whole river.

As an example of possible benefits, assuming that the drill line falls on a certain isohaline near Urbanna, we estimate that moving this line 1‰ down river in summer would be the equivalent of 5 miles on the river in this vicinity; at least 1000 acres of oyster ground would be affected. Assuming a very modest production of 50 bushels per acre per year, one can obtain a benefit of 50,000 bushels per year at $4.00 per bushel. If drills, and possibly other pests and diseases with about the same distribution, were eliminated from the Rappahannock River benefits would be enormous. Then, if efficient culture methods were inaugurated benefits could reach into millions of dollars. The whole lower half of the oyster-producing area would be opened to private and public production on a self-sustaining basis--assuming present spatfall levels are maintained. On the other hand, oyster beds are appreciably deeper below Towles Point than above it. Sanctuaries of high salinity waters on deep beds may be a major reason why the "drill line" seems to diverge little from the Towles Point area in wet and dry seasons.

Unforseen problems with oysters and other organisms might arise also. Changes in summer salinities would be minimal at the upper end of the oyster-growing area hence should not affect oyster growth and fattening appreciably.

SUMMARY

The biological effects of Salem Church Dam on oysters and their associates is projected. The moderating effect of water storage on seasonal extremes of salinity is expected to permit penetration of oyster pests and diseases to higher levels of the river.

For mitigation of such damages, planned releases in spring in wet years have been translated from riverflows to salinities. To maintain drills and other pests at their present levels near Towles Point, a discharge of 6500 cfs for a 20 day period near 1 May in wet years is requested.

Benefits from summer releases, in years of average flows when

the reservoir fills by 1 May, are possible with relatively small increases in flow. One thousand cfs through July, August and September seems adequate if conflicts with recreational facilities from drawdown are not excessive.

Difficulties in translating riverflow to salinities, scarcity of spring salinity data, questions about stratification at high riverflows--all are problems which could easily be resolved with a model but are difficult to determine in the river itself. Refinements of data and estimates are to be expected as knowledge of estuaries increases. With adequate arrangements of salinity monitoring downstream plus feed-back to the dam operators, which will be necessary and should be planned as part of the project, it should be possible to vary releases to produce the desired results with a minimum of drawdown or other disruptions of reservoir operations. It is also necessary that more adequate hydrographic observations be made prior to final project planning and construction. These requirements will be set forth in a separate report.

Composition of the Virginia Institute of Marine Science Salem Church Dam Study Committee.

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Addenda to Salem Church Report

List of References and Exhibits Necessary to

Supplement these Reports

(All presumed to be in hands of agencies involved)

1. Ltr. of Bureau of Sport Fisheries and Wildlife dated 7 Sept. 1962 describing Salem Church Project and problems involved.

2. Computation sheet of 19 Dec. 1963 by C. E. showing total riverflow from October to April inclusive and ranking of 18 wettest years of 54 of record.

3. C. E. rule curves for 54 years showing drawdown and manipulated release for years of mitigation benefits and dry years.

4. Sources of Hydrographic Data for Rappahannock River from 1948 to 1963.

5. C. E. memo dated 25 Aug. 1964 describing operation of Salem Church as related to oyster production.

TABLE I

Days required to obtain kills of *Urosalpinx cinerea**

(From experiments by Langley Wood 1963 & 1964)

Salinity	13°C		20°C	
	50% Kill	100% Kill	50% Kill	100% Kill
8.1	13 & 18	24+, 35+	6 & 12	16-23, 33
11.4	No Kill		No Kill	
15.2	No Kill		No Kill	
18.2	No Kill		No Kill	

*No appreciable mortality occurred at any salinity except 8.1

TABLE 2

Wet Years of Record*

(from Corps of Engineers Computation Sheet dated 18 December 1963)

	Sequences of wet & dry years	cfs Oct. to Apr. inclusive	Rank by riverflow	Drawdown Characteristics
1908	2 in a row	19,171	6	
1909		15,150	19	
1912	5 year gap	15,218	18	
1918	6 year gap	18,372	9	
1925		17,330	11	
1927	2 in a row	17,080	12	
1928	4 year gap	15,310	17	
1933		21,250	5	
1935		18,054	10	
1936	4 in a row	21,869	4	
1937		21,961	3	
1938	4 year gap	17,019	15	
1943	5 year gap	25,534	1	
1949		24,150	2	OK No spring salinities
1951		18,516	8	OK only because wet June
1952	3 in a row	16,313	16	Not OK, very dry summer
1953	4 year gap	18,680	7	Not OK, very dry summer
1958		16,898	14	OK

*No salinity records are available for the years prior to 1943 hence only the last five years listed can be used to compare river runoff. 1949 and 1958 are the only two years of suitable runoff and drawdown conditions for comparing salinities. Considered biologically, 1948 should have been included as a wet year and is also satisfactory in terms of drawdown. Spring salinities are available for 1958 only.