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PRELIMINARY GROUND-WATER REPORT FOR CAMP LEJEUNE, N. C.

By

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P. O. Box 10602
Raleigh, N. C.

October 23, 1958

Officer-in-Charge
Public Works Department
Camp Lejeune, N. C.

Dear Sir:

This preliminary report is submitted in accordance with provisions of Contract NBy-7595, dated September 11, 1958.

The report summarizes the geology and the ground-water conditions at the Marine Corps Base, Camp Lejeune, North Carolina, and designates the number, location, and depth of test holes that are to precede new production wells. Data required from the well contractor and specifications for drilling of test wells are included.

Although locations for the test wells and for the "follow-up" production wells are pin-pointed on the attached maps, geologic conditions do not dictate such precision in location. For example, the four proposed test holes to be drilled to salt water may be moved 1,500 feet in any direction without losing any value. The other test holes may also be moved limited distances at the discretion of the Officer-in-Charge.

Sincerely yours,

Harry E. LeGrand
Consulting Geologist

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INTRODUCTION

This is a preliminary report pertaining to ground-water conditions at the Marine Corps Base, Camp Lejeune, North Carolina. Its main purpose is to serve as a basis for the drilling of about twenty-two test holes that are to precede the drilling of future permanent wells in various areas at the Base.

This report outlines the problems involved in obtaining an adequate quantity of good quality water from wells and suggests locations for test holes at places where new permanent wells might be drilled. Suggestions are made concerning specifications for the test drilling. Following the completion of the test drilling program, a comprehensive final report is to be prepared. The final report will evaluate all data, including that obtained from test drilling, and recommendations will then be made as to the permanent, raw-water supply.

GEOLOGY AND NATURAL GROUND-WATER CONDITIONS

All of Onslow County is underlain by sediments that were deposited in or near the ocean. These sediments are composed of sands, clays, marls, and layers of consolidated rocks, such as limestone and sandstone. There is a tendency toward layering, and most of the beds are nearly flat but slope gently toward the coast. These sediments are more than 1,800 feet thick and lie on a floor of hard dense rock such as granite. Only the uppermost few hundred feet of the sediments are important to this discussion, in view of the fact that the deeper sediments are saturated with salty water. The block diagram on the following page shows the general nature of the geology at the Base. The sediments at the surface are chiefly sands that extend to a depth of 10 to 50 feet. The lower part of the "surface-sand unit," locally containing some clay, overlies sediments of Tertiary age. These Tertiary sediments may be considered as a unit and are composed of loose shells, sands, marls, and consolidated shell beds. It includes chiefly the Castle Hayne formation, but the uppermost part is the Yorktown formation. Together, they will hereinafter be referred to as the "limestone unit." Locally, the Yorktown contains blue clay, but the extent of the blue-clay zone in Onslow County has not yet been determined. Down stream from Jacksonville the channel of New River cuts into the Yorktown formation. Below the Castle Hayne (at a depth of more than 250 feet) is the Peedee formation, composed of dark sands and clays and thin limestone beds.

All sediments below the water table are completely saturated with water. The water table lies within 10 to 20 feet of the land surface in most places and is in the surface sand. Beds of clay, and perhaps marl, tend to separate the more permeable sand and shellrock beds so that several artesian horizons, or zones, occur in the limestone unit. None of the artesian beds are perfect, and there is considerable leakage of water between them where a significant hydraulic gradient exists. This situation arises from the fact that the clayey confining beds are not completely impermeable and from the fact that some beds are not persistent but are somewhat lenticular.

Only in the upper part of the limestone unit is there a significant movement of artesian water under natural conditions. Since the limestone unit lies in the channel of the river and since the artesian levels are slightly higher than the level of the river, there is leakage of water from the limestone into the river. A very large part of the precipitation infiltrates into the surface sand to become underground water. After infiltrating downward to the water table, this water moves laterally toward the nearest surface stream.

WITHDRAWAL OF WATER FROM WELLS

With regard to withdrawal of water from wells at the Base, two aspects of the matter need consideration. One concerns the ability of individual wells to yield water, and the other concerns the ability of the aquifer to yield an acceptable and adequate supply of water perennially.

Most of the wells range in yield from 2 to 10 gallons a minute for each foot of drawdown. This compares unfavorably with yields in other parts of the Tertiary limestone unit extending from the Albemarle Sound through Florida, where the average is greater than 20 gallons a minute per foot of drawdown. The limestone unit, in general, is characteristically a shellrock which is made permeable by the removal in solution of the abundant shell material. At the Base the shellrock to a depth of about 100 feet is rather thin and perhaps contains sand in its open pore spaces. At any rate, the pumping of sand from the few open-end wells has led to the installation of screened wells to prevent the inflow of sand. The permeability of the sand beds is much less than that of the shellrock beds. Another reason for the low-yielding wells is that at a depth of 80 to 100 feet, which is about the average depth of the bottom screen, the aquifer is only partially penetrated. By utilizing all permeable beds to a depth of 250 feet, much greater yields could be realized. This fact, however, must be tempered with the possibility that water unsuitable to present treatment facilities would be withdrawn.

The safe yield of the aquifer may be considered as the [illegible] of water that can be pumped perennially without bringing in a water of inferior quality. Before the first wells were drilled the hydraulic system in the aquifer was in balance; the natural discharge into New River and perhaps other places was equal to the recharge, and both the water table and artesian levels were more or less fixed in position. When the first wells were drilled this equilibrium was disturbed as water was drawn from storage in the artesian system. Water levels have declined as more wells were pumped. A sufficient amount of water has been drawn from storage to depress the artesian levels over a large area. The water levels will stabilize only when the natural discharge is reduced and the recharge is increased by an amount equal to the amount discharged by the wells.

We have referred to the limestone unit as an artesian system, and its early response to pumping wells bears this out. However, there is no perfect seal or confining bed above the aquifer, and, as a result, water from the surface sand moves into the aquifer even through clay beds that occur locally. It is fortunate that this condition prevails in the Hadnot Point area; otherwise, the artesian levels would have lowered much more than they now have, and very likely salty water from the river would have spoiled the aquifer in this area.

With the available data it is impossible to determine accurately the recharge to the aquifer. However, some rough estimate can be made. The infiltration capacity of the surface sand is great. Perhaps between 30 and 40 inches of rain a year reaches the water table in the saturated sand. If the materials extending from the surface sand down to the aquifer are somewhat permeable, a great part of this water will move downward into the limestone unit in the vicinity of pumped wells because the artesian head is considerably less than that of the water table in these places. Under present conditions the downward movement into the limestone is so slow that much of the water in the surficial sand is shunted laterally to a surface stream and thus is not available for recharge. The amount of recharge resulting from downward leakage out of the surface sand is perhaps slightly more than one million gallons a day per square mile in the vicinity of each of the well fields except at the Rifle Range where it may be less. In addition to recharge by downward leakage, there is also recharge by upward leakage from beds that underlie the level of the lowest well screens. In areas where water is not pumped, the artesian pressure tends to increase with depth. Therefore, there is natural upward leakage even through clay beds. When the head is lowered in the aquifer penetrated, the upward leakage is greatly increased. The combined effects of upward and downward leakage into the aquifer has caused the water levels in the aquifer to approach a stabilized condition with less drawdown than would be the case in a perfect artesian system. Precautionary measures of limiting the drawdown and dispersing the wells have been taken to prevent overpumping. The heavy pumping in the Hadnot Point area is resulting in a gradual decline of the water level in the vicinity of some wells in this area. Data to be collected before the final report is prepared may indicate the position at which the water level will stabilize in the Hadnot Point area.

CHEMICAL CHARACTER OF WATER

The chemical character of underground water varies considerably with respect to depth and geologic formation. Originally all the beds contained sea water, but in the relatively recent geologic past the fresh-water head has been great enough to push the salty water coastward and seaward to some extent. Salty water has been completely flushed from the uppermost beds, but beds deeper than about 400 feet have been only partly flushed of their original salty water. The beds from which salty water has been flushed now yield water that reflects the chemical character of the rock materials in which it occurs.

Water in the surface sand is soft and contains less than 30 parts per million of dissolved solids. It contains some free carbon dioxide, resulting in a pH value varying between 5.0 and 7.0.

Water in the limestone unit is a hard, calcium-bicarbonate water, typical of that in the Tertiary limestone unit extending from the Carolinas into Florida. Except where there is some indication of salt water contamination, the water in the limestone unit commonly ranges in hardness from about 100 to 250 parts per million. Both iron and hydrogen sulfide occur in objectionable quantities at certain places and certain depths. These features are discussed appropriately under the discussion of each area of the Base.

Very little is known about the water in the Peedee formation, the top of which lies at a depth of 250 or perhaps 350 feet below the ground. This formation contains fresh water at Richlands; it is a soft, sodium bicarbonate water, having been softened through cation exchange by natural movement through the glauconite (natural zeolite) sands of the Peedee. At the Base, it is likely that the cation exchange process is complete in the Peedee and that there is no significant calcium bicarbonate hardness. However, it is also likely that the water is salty and unsuitable for use. The proposed deep test holes should reveal the chemical character of water from this formation.

SALT-WATER CONTAMINATION

Where the ancient sea water has been completely flushed out of the underground formations in eastern North Carolina the chloride content of the water is less than about 25 parts per million. Where the chloride content is higher than 25 parts per million there is a suggestion that saltier water is near. Since there are about 19,300 parts of chloride in a million parts of sea water, chloride provides a better indication of salt-water contamination than any other chemical constituent.

There are two ways in which the limestone aquifer at the Base can become contaminated by salt-water intrusion. These are (1) lateral encroachment of water from New River and its tributaries and (2) vertical encroachment from the underlying salt-water beds.

Consideration of possible contamination of the water supply by encroachment of water from New River can be centered on the following points. Although New River does not have the salinity of sea water, it is brackish during much of the year. The degree of its salinity is not very important because it could make an aquifer unusable whether it contains 2,000 or 20,000 parts per million of chloride. New River and the mouthward parts of its tributaries have cut through any impermeable beds that were present and are now entrenched into the limestone aquifer. If withdrawal of well water is concentrated close enough to the river so that a hydraulic gradient is established from the river to the center of pumping, salt-water encroachment will occur. Fortunately, proper caution has been taken in the planning of the water supply to prevent lateral encroachment. For example, in the Hadnot Point area the policy has been to limit the drawdown in each well and to locate wells at considerable distances from the salt-water estuaries. As a result of these practices, no contamination has yet occurred. The present data suggest that fresh water of the aquifer is discharging into the river and that the water level has not been lowered sufficiently to reverse the gradient--that is, from the river to the aquifer. A few small observation wells between the river and the production wells would give the water-level measurements needed to clarify this point. The only place where lateral encroachment has actually occurred is at Well 109 on Onslow Beach. This contamination is discussed in the section dealing with Onslow Beach.

The other way in which salt water may reach the aquifer is by upward movement from beds containing salt water. In discussing this point, it is necessary to understand the significance of the relative density of salty water. Since sea water has a specific gravity of 1.025, forty feet of sea water will balance forty-one feet of fresh water. This difference in specific gravity of fresh water and sea water has led to the general rule of 40 to 1 ratio. Where the rule can be applied, the depth in feet below sea level to the contact between fresh and salt water theoretically will be 40 times the number of feet the static level of fresh water is above sea level. The rule cannot be applied to conditions at the Base because of the gradational salinity of water in the ground and because of the absence of homogeneous strata. Nevertheless, it is of value to know that the lowering of the water level in the aquifer a few feet could cause, under certain conditions, the salt water in the underlying bed to rise many feet. The only place where vertical contamination is known to have occurred is at Well E, Camp Geiger. The policy of dispersing wells and of limiting the drawdown in each well, as is the practice at the Base, is the proper precautionary measure to take in preventing vertical contamination. However, more information is needed concerning the depth to salty water and the relative permeability of the materials between the salty water and the zone from which the wells now draw water. The four test holes to be drilled into the salty water zone should produce valuable data.

SUMMARY OF THE PROBLEMS

The overall objective of developing the water supply at the Base is to obtain a perennially adequate supply of acceptable chemical quality in the most economical way. This objective is not reached by merely considering the yield of one or even all wells and the treatment that would be necessary. Rather, a number of delicately interdependent factors need consideration separately and collectively. These factors may be grouped in terms of the (1) quantity and (2) chemical quality of the water.

The strict adherence to certain chemical aspects of the water - freedom from chloride contamination and water suitable to present treating facilities - places limitations on the quantity of water available from the aquifer and from wells.

All water problems are in a sense economic problems, for with a given amount of money, a satisfactory supply of water can be had anywhere in the world. With this thought in mind, we note that the fear of chloride contamination has caused a wide spacing of wells and has caused limitations on the drawdown and yield of the wells. This, in turn, has resulted in a greater expenditure of funds than would have been the case if the problem of chloride contamination were not present. Can wells be spaced closer and can the drawdown and yield of individual wells be increased and still maintain a safe adequate supply? Good judgment has been exercised in developing the water supply at the Base, and a reasonable margin of safety exists insofar as protecting the quality of the water. The deep test holes that are to be drilled should give valuable information about the salt water and fresh-water boundaries and about the possibility of salt-water contamination. The more that is known about the positions of these boundaries the greater can be the withdrawal of water while maintaining a margin of safety.

Another economic problem concerns the relatively poor specific capacity of the wells (gallons per minute per foot of drawdown). This becomes a significant matter in view of the fact that the gravel-wall type wells, which have been installed, are expensive. The wells have been drilled by competent well contractors, and there is no suggestion that the wells are improperly construted. Yet some improvement in the economics of wells--either a better specific capacity or reduced cost per well--is one aim of the test drilling program. By having electric logs made and samples of rock materials studied from each test hole, the proper placing of well screens and other well construction techniques can be assured.

One reason for the low specific capacity of the wells is the necessity for selecting only those water-producing zones that will yield a water that can be treated satisfactorily at the present treatment plants. For example, some zones of high permeability yield water with excessive amounts of hydrogen sulfide--others with excessive amounts of iron or hardness. It appears more economical, generally speaking, to sacrifice "well yield" in order to obtain the type of water that can be best treated at each plant.

SPECIFICATIONS FOR THE TEST WELLS

The contractor must drill test wells at places approved by the Public Works Officer. The conditions of the drilling and the results to be obtained follow:

1. Drill an open hole approximately 10 inches in diameter by the rotary clay seal method to depths designated by the Navy or its consultant.

2. Samples of all materials shall be collected at 10-foot intervals, regardless of the change or lack of change in the character of materials. The samples shall be placed in 1-pint transparent plastic bags and labelled in indelible ink, such as "magic marker."

3. The contractor shall furnish a driller's log showing the character of materials penetrated.

4. Upon completion of the drilling of the test well, the contractor shall make an electric log showing continuous self-potential and resistivity curves.

5. The contractor shall collect and have analyzed samples of water from all water-bearing strata of interest so as to accurately show the quality of water from each stratum. These analyses shall include the pH of the water and in parts per million the total hardness, iron, chloride, alkalinity, and hydrogen sulfide.

6. The test well shall be sealed in an approved manner to prevent interchange of water between the strata after the tests have been made.

7. The above-mentioned samples, driller's log, and water analyses shall be available for inspection at all times and copies provided upon completion of the test wells.

8. After analyzing the information from the test wells, the contractor shall make recommendations for the design of a future permanent well. His recommendations shall include the appropriate depth, details of construction, length and location of screens, and an estimation of the quantity and quality of water that can be obtained from each water-bearing stratum and from the completed well.

TEST WELL PROGRAM

Test Hole Number	Area of Location	Proposed Depth	Number of Water Samples
T-1	Hadnot Point	475	4
T-2	Hadnot Point	225	3
T-3	Hadnot Point	225	3
T-4	Hadnot Point	225	2
T-5	Hadnot Point	225	2
T-6	Hadnot Point	225	2
T-7	Hadnot Point	225	2
T-8	Hadnot Point	300	4
T-9	Tarawa Terrace	185	3
T-10	Tarawa Terrace	185	2
T-11	Tarawa Terrace	185	2
T-12	Montford Point	350	3
T-13	Montford Point	250	3
T-14	Montford Point	200	2
T-15	Camp Geiger	475	4
T-16	Camp Geiger	200	2
T-17	Camp Geiger	200	2
T-18	Rifle Range	300	3
T-19	Rifle Range	150	2
T-20	Courthouse Bay	115	2
T-21	Courthouse Bay	115	2
T-22	Onslow Beach	150	2
	Total	5,385 feet	56

TEST WELL PROGRAM - Continued...

If available funds are not adequate to cover the cost of drilling 5,335 feet, handling 56 water samples, and running 22 electric logs, 3 wells could be eliminated in the following way:

T-1 can be moved to the site of T-2, T-12 can be moved to the site of T-13, and T-15 can be moved to the site of T-16. Thus, the total footage can be reduced to 4,710 feet, the water samples to 48, and the number of electric logs to 19. Also by keeping an interval of two weeks' time between the drilling of certain wells so that the results can be evaluated, other reductions in footage and perhaps in water samples may be made. For example, the drilling contractor should plan his work so that:

T-4 and T-6 should not be started within two weeks following the completion of T-3 and T-5.

T-11 should follow by two weeks the completion of T-9 and T-10.

DISCUSSION OF SEPARATE AREAS

On the following pages are brief discussions of the well-water situation at the separate areas where water is used. The discussions cover only those points that are pertinent to the test drilling and to future development of wells.

Hadnot Point

If hydraulic characteristics of earth materials to a depth of about 400 feet were precisely known at Hadnot Point, as well as at other areas of the Base, it would be possible to have optimum conditions concerning the relationship between withdrawal of water, drawdown, spacing of wells, and maintaining a perennially safe supply. The following paragraph diverts slightly from the pattern of discussion but is still pertinent to the problems at Hadnot Point.

> Within the scope of plans of almost all ground-water hydrologists on a project is a pumping, or aquifer-performance, test. This test is made by systematically observing water-level fluctuations when a well pump is turned on and after it is turned off. From the tests it is hoped that the coefficient of transmissibility and the coefficient of storage may be obtained. The coefficient of transmissibility may be defined as the rate of flow of water in gallons per day through a vertical strip of aquifer one foot wide, extending the full saturated thickness of the aquifer, under

a hydraulic gradient of 100 percent. The coefficient of storage is the volume of water the aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It might be as much as 25 percent in a water-table aquifer, such as the surface sand, where most of the water is obtained by dewatering the material. It might be a small fraction of one percent in the artesian limestone unit where water is yielded by elastic adjustment to changes in pressure. It is possible to determine the drawdown at future dates and at varying distances under varying conditions of pumping by using these aquifer characteristics. However, to get valid results, certain ideal conditions must exist. For example, the aquifer must be homogeneous and must transmit water equally well in all directions; the well must penetrate the complete thickness of the aquifer; and water must be drawn entirely from storage. In the Hadnot Point area, as well as in the other areas, the character of rock materials and, therefore, the ability of the materials to transmit water, varies greatly from place to place. This is reflected in the range in yield from well to well. On the basis of the present wells, the coefficient of transmissibility ranges from about 5,000 to about 25,000, but the values are low because the aquifer is only partially penetrated since wells are screened only in some of the permeable zones. The coefficient of storage increases with time. At first it is small because water is drawn from storage in the artesian system where the response to a change in head is due solely to compressibility of the aquifer material and of the water. Since the aquifer at Hadnot Point is not completely confined and not completely separated from the surface sand, downward leakage of water into the artesian beds is by gravity drainage. Therefore, recharge from the surface sand gives the aquifer a storage capacity many times greater than a pumping test would indicate. It is clear that an attempt to get quantitive results from aquifer performance tests at Hadnot Point would be misleading.

The wells in the Hadnot Point area are dispersed sufficiently so that there is no single composite cone of depression in the water level. It is true that some lowering of the water level at any of the wells is partly due to the influence of pumping nearby wells. This is a natural consequence of the development of a well field and, in itself, is not detrimental. The control of drawdowns to prevent salt-water encroachment has resulted in a larger number of wells and a greater dispersal of wells than would have been the case if the concern about salt water contamination were not real.

Most of the wells are cased at intervals between 60 and 190 feet. The yield varies between 3 and 12 gallons per minute per foot of drawdown. Treatment adequately handles the hardness and iron content. The hydrogen sulfide content appears to be less than that at the same depth elsewhere.

The chloride content of water from all wells is low, and there is no indication that salty ground water is moving toward the well field. The test wells to be drilled should furnish much needed information about the earth materials and the quality of the water below 190 feet, which is about the deepest zone from which water is drawn. The final report will evaluate this information in terms of possible vertical encroachment of salt water. Very careful location of wells at points away from brackish-water streams has prevented lateral encroachment.

The recommendation made by Pitometer Associates for new production wells to be located along the sand road south of Piney Green is endorsed. As suggested in the well table, test holes T-4 and T-6 should be the last of all the test holes drilled. This suggestion is made because a study of the results of earlier test holes would be desirable in evaluating the entire water supply of the Hadnot Point area. To get greater specific capacities from future wells without increasing the hydrogen sulfide content of the water is one objective.

Tarawa Terrace

Seven wells have been in operation at Tarawa Terrace, although Well 4 has been abandoned because it pumped sand. Some driller's logs and other records are available, but these records have only limited use for the following reason. Three sets of well numbers have been used - the driller's numbers, the site numbers, and the present numbers. Thus far, it has not been possible to relate these numbers so that a specific well record can be identified with a particular well.

Of the 5 wells along Lejeune Blvd. only Well 1 now furnishes more than 100 gallons a minute. It is thought that the poor yields of these wells are due to poor well construction rather than to a change in permeability. Most of the water from these 5 wells comes from depths varying from 50 to 100 feet. The water is typically hard and contains slightly objectionable amounts of iron and hydrogen sulfide.

Wells 6 and 7 on the Bell Fork Road need separate consideration. Perhaps these wells draw much of their water from depths between 150 and 200 feet. At any rate, the yields are relatively good, but the chemical quality is very poor. Water from both wells contains more than 4 parts per million of hydrogen sulfide. Moreover, Well 6 has nearly 200 parts per million of chloride and Well 7 nearly 50 parts. Water from these two wells is not suited for present treatment facilities, and in no case can this water be treated economically.

The overall objective is to increase the water supply and at the same time eliminate undesirable water that approximates in chemical character that from wells 6 and 7.

It is recommended that 3 test wells be interspersed between existing wells on Lejeune Blvd. These test holes should be 185 feet deep and at least two samples of water should be taken from each hole - one sample from the best water-bearing zone between 50 and 100 feet and one sample from the best water-bearing zone below that zone.

Montford Point

Wells at Montford Point draw water only from the upper part of the limestone unit, most of the wells having two short screens at various depth-intervals between 50 and 100 feet. The wells vary in yield from 2 to 7 gallons a minute per foot of drawdown, and only one or two wells are pumped at more than 125 gallons a minute. Water in the 50 to 100-foot zone is treated effectively by the zeolite process and is chlorinated. The raw water varies in hardness from about 150 to 200 parts per million and in iron from about 0.4 to 1 part per million. It contains less than 1 part per million of hydrogen sulfide. The chloride content is less than 20 parts per million.

According to results of two test wells drilled deeper than 100 feet at Montford Point, the hydrogen sulfide content seems to increase greatly with increased depth in the limestone unit. The yield per well also would be expected to increase greatly with depth. Therefore, these two countering factors need careful consideration prior to the drilling of production wells in the area.

It is understood that the chloride content of water from the well near the White Cemetery was only 28 parts per million. The well was an open-end hole from 164 to 227 feet. It had a yield of 10 gallons a minute per foot of drawdown.

Recommendations concerning the test holes to be drilled are found in the well table.

Camp Geiger

A very delicate relationship exists between the fresh-water and salt-water zones at Camp Geiger. In general, the limestone unit to a depth of 100 feet contains water that is low in chloride, but in the highly permeable shellrock between 100 and 200 feet enough chloride is present to be objectionable or to cause concern about the possibility that it might increase to objectionable amounts.

The reason for the nearness of brackish water to the land surface in the area of Camp Geiger and Peterfield Point is not clear. One possible explanation follows. During the interglacial periods of the Ice Age the sea encroached on Onslow County and drowned it. During these times sea water moved easily into the permeable shellrock. The sea water entered the shellrock where it occurs in the present river channel and then moved laterally, pushing the former fresh water westward. Since the sea has withdrawn to its present position, the salt-water head has been decreased and is now slightly less than the fresh-water artesian head. However, the difference in head has not been great enough for the fresh water to completely flush out the sea water. The fact that the chloride content is only a few hundred parts per million at Wells A and D indicates that the flushing process is almost complete and that the chloride content in this zone at some places may be low enough to be acceptable in the water supply. In fact, the wells at Peterfield Point are screened between 100 and 180 feet and yet will yield water with a fairly low chloride content. If this explanation for the occurrence of brackish water is correct, there is a possibility that fresh water may be found at a depth varying between 200 and 400 feet.

The great permeability of the shellrock below 100 feet is indicated by the high specific capacity of Wells A and D, as well as those at Peterfield Point. Well A yields 30 gallons a minute per foot of drawdown, and Well 4 at Peterfield Point is reported to yield nearly 60 gallons a minute per foot of drawdown.

One objective at Camp Geiger is to determine, with some degree of finality, whether water of acceptable chemical quality can be found deeper than 100 feet. If only water of poor quality is found in this permeable zone, increased withdrawal of water from the 50 to 100-foot zone must be carefully planned. The fact that the water from Well E now has slightly more than 200 parts per million of chloride is a matter that deserves consideration. The well appears to have been "salted" by upward movement of water from the lower zone. This situation points out that salt-water contamination is a matter that should continue to get the attention that it has in the past.

Test holes should be drilled to depths as specified in the well table. Samples should be collected in each well between 50 and 100 feet, between 100 and 200 feet, and elsewhere as appears appropriate.

Rifle Range

Three different zones of the limestone unit have been tapped at the Rifle Range. Wells S-1 and T-1 are screened at intervals of

70 to 80 and 63 to 73 feet respectively. Both wells yield more than 10 gallons a minute per foot of drawdown and attest to the high permeability of the consolidated parts of the limestone unit. The most objectionable features of water in this zone are the excessive iron and hydrogen sulfide contents. Well S-1 contains 3.4 part per million iron, and Well T-1 contains 6.0 parts per million iron. Well S, screened at 4 different intervals between 75 and 130 feet, yields 10 gallons a minute per foot of drawdown. Water from this well contains less iron and hydrogen sulfide than that from the shallower wells. Well T, which has been abandoned, was screened at the following depth intervals: 382-392, 412-422, and 442-452. The yield was only about 4 gallons per minute per foot of drawdown. A complete chemical analysis is not available, but the water is reported to have had a strong odor of hydrogen sulfide.

Even though the well field lies fairly close to New River, chloride contamination of the wells is not likely to be a serious consideration for two reasons. First, impermeable clays of the Yorktown formation overlie the limestone unit to a depth of 40 to 60 feet, and these clays probably underlie New River near the Rifle Range; the clays should be a partial barrier to any tendency toward salt-water encroachment. In the second place, the relatively high yields of the wells with the limited drawdown should discourage salt-water encroachment.

The chief problems do, however, pertain to the quality of the water—the iron content, the high sulfide content, and the ever present hardness content.

It is recommended that the first of two test holes at the Rifle Range be drilled to a depth of 300 feet and the second well to a depth of 150 feet. Samples of water should be taken from the 60 to 80-foot zone, from the most permeable zone between 90 and 150 feet, and in the case of the deeper test hole, from one deeper zone.

Courthouse Bay

Both Wells V and W draw water through wells screened between depths of 30 and 60 feet at the top of the limestone unit. Both wells yield more than 5 gallons a minute for each foot of drawdown, and thus yield is not a problem. According to analyses of October 24, 1957, Well W had an iron content of 1.8 parts per million as compared with Well V of 0.6 part per million. Well W had a hydrogen sulfide content of 0.4 part per million as compared with Well V of 1.0 part per million. These variations in chemical character are not understood at present.

It is recommended that each of the 2 test wells be drilled to a depth of 115 feet. Samples of water should be taken from the 30 to 60-foot zone and from the most definite water-bearing zone between 70 and 115 feet.

Onslow Beach

Although no test well was originally designated for Onslow Beach, an increase in salt content of Well 22 at the water plant is justification for one test hole.

CLW

Both Wells 22 and 23 are about 65 feet deep and each is screened at the depth intervals of 30 to 40 feet and 52 to 62 feet. The limestone unit is more consolidated here than at Hadnot Point, and it is likely that open-end wells into the shellrock would be satisfactory. Production from this zone is relatively high. For example, Well 22 gives about 10 gallons a minute per foot of drawdown and Well 23 about 6 gallons a minute per foot of drawdown.

The water in this shallow zone is hard and contains considerable iron and hydrogen sulfide. Zeolite treatment and chlorination reduce the undesirable mineral matter to an acceptable point. An analysis of August 22, 1957, showed that Well 22 had a chloride content of 136 parts per million as compared with about 13 parts per million when the well was first drilled. In view of the fact that the Intracoastal Waterway has cut into shellrock of the Yorktown formation less than 2,000 feet from this well, it is likely that high tides have pushed salt water laterally in the shellrock toward the well. If the chloride content of water from this well continues to increase, it should be abandoned.

It is recommended that the test well be drilled to a depth of 150 feet and that at least two samples of water be taken -- one in the upper part of the shellrock (30 - 60-foot zone) and another between 70 and 150 feet.