Hydrogeologic Reconnaissance of San Nicolas Island California

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1539-O

Prepared in cooperation with the U.S. Department of the Navy

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By W. L. BURNHAM, FRED KUNKEL, WALTER HOFMANN, *and* W. C. PETERSON

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CONTENTS

ILLUSTRATIONS

TABLES

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

HYDROGEOLOGIC RECONNAISSANCE OF SAN NICOLAS ISLAND, CALIFORNIA

By W. L. BURNHAM, FRED KUNKEL, WALTER HOFMANN, and W. C. PETERSON

ABSTRACT

San Nicolas Island, about 60 miles west of Santa Catalina Island and about 90 miles southwest of Los Angeles, is a gently folded, intensely faulted elevated segment of the earth's crust; its highest point is 907 feet above mean sea level. The major part of the island is composed of marine sediments and some intrusive dikes. Overlying the older consolidated rocks are minor veneers of marine terrace and alluvial slope-wash deposits and superficial to massive deposits of windblown sand.

The principal sources of potable ground water on the island are the deposits of windblown sand. These have been subdivided into four subunits on the basis of lithologic, absorptive, and water-yielding character as follows: Active dune sand; vegetated, friable, fresh sand not now in transport; indurated, compacted, noncemented sand now undergoing erosion chiefly by deflation; and cemented, deeply weathered sand.

All ground water on San Nicolas Island originates from precipitation and percolates downgradient in response to gravity. The chemical quality of the ground water already developed is marginal or inferior for drinking water according to standards of the U.S. Public Health Service.

Two areas toward the west end of the island, which are underlain by windblown sand, were considered as potentially suitable for additional ground-water development. One of the areas has four producing wells, but they are closely grouped, and the geologic and hydrologic properties are poorly known. Drilling of seven test holes, of which two were tested by pumping, indicated that the windblown sand deposits were above the saturated zone and that yields from the underlying consolidated rocks were too low for development as a water supply for the naval installation.

Study of precipitation, and of water lost by interception or used to supply the deficiency in soil moisture indicates, for the period 1933–55, that the average amount of water left annually to produce surface runoff or recharge the ground-water body was 1.5 inches in the western third, 0.8 inches in the northeast, and 2.1 inches along the south coast. Most of the water in the south coast area is surface runoff from the steep slopes, and discharges directly into the ocean. These are maximum amounts of water that are available; the amounts that could be developed as water supply are considerably smaller. Large amounts of storage would be needed, and even if sufficient surface and ground-water storage sites exist, losses by evaporation and seepage would decrease the amounts of water available for use.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

This report presents findings of a geologic and hydrologic reconnaissance of San Nicolas Island, Calif., made by the U.S. Geological Survey during the autumn and winter of 1956–57 at the request of the Department of the Navy. The purpose of the investigation was to study the possibilities of developing a potable water supply.

The ground-water study included reconnaissance geologic mapping of the entire island to determine the extent and character of the unconsolidated deposits and the water-bearing character of all the geologic formations, collection and study of all existing geologic and hydrologic data pertaining to wells and springs, and preparation of a report and map showing the geologic and hydrologic features of the island.

The ground-water geology and hydrology were investigated by W. L. Burnham, under the immediate direction of Fred Kunkel, geologist in charge of the Long Beach subdistrict office of the Ground Water Branch, and under the general supervision of G. F. Worts, Jr., former district geologist for California. Chemical analyses of water from the island were made by the U.S. Geological Survey laboratory at Sacramento, Calif.

The part of this report concerned with precipitation and recoverable water was prepared by Walter Hofmann, district engineer of the Surface Water Branch, for California, and W. C. Peterson, engineer, Surface Water Branch, California. It gives an estimate of the total quantity of water that is available on San Nicolas Island to produce streamflow and to recharge the body of ground water.

On the basis of the reconnaissance reported herein nine sites for test wells were selected (pl. 1). At seven of the nine sites test wells were drilled by the Roscoe Moss Co. during September–November 1960 under contract with the Department of the Navy. Technical assistance in logging, developing, and testing the wells was by R. W. Page of the Ground Water Branch. The results of the test drilling are described in pages 20–24.

PREVIOUS INVESTIGATIONS AND ACKNOWLEDGMENTS

The earliest published reference to San Nicolas Island is an anonymous (1857) article of only historical interest. This was followed by numerous anthropological and archaeological studies, the earliest of which was by Shumacher (1875) and the most complete by Bryan (1930) and Meighan and Eberhart (1953). Meighan and Eberhart supplied a complete list of published references to the island. However, none of these articles contains more on the subject of water than indirect references to springs.

The earliest published reference to the geology of San Nicolas Island is by Whitney (1865, p. 184). He gives a brief description of the island and a statement that the rocks on the island are predominantly sandstone. The first reference to water on the island is by Bowers (1890), who states, "There is an 'abundance' of water on the island, but it is slightly brackish". Smith (1900) discusses the general geology of all the islands of southern California but makes no references to the ground or surface waters.

Prior to its acquisition as a military reservation, the island was used at times as a pasture for sheep and was visited from time to time by archaeologists and fishermen. The extensive kitchen middens and numerous artifacts are abundant evidence that the island has supported a large and probably permanent Indian population over a long period of time, and this fact suggests the existence of a perennial supply of potable water.

In addition to the published references, J. E. Upson of the U.S. Geological Survey visited the island in 1942 to assist the Navy in preliminary planning for development of the water supply; however, no formal report was prepared. In 1950–51 C. F. Hostrup, consulting engineer, Los Angeles, Calif., assisted the Navy in the engineering phases of developing the island's water supply. The unpublished notes and drawings for both of these studies were consulted in the preparation of this report.

During 1955–56, J. G. Vedder, project chief, and R. L. Harbour, R. M. Norris, R. J. Burnside, N. C. Privrasky, and D. J. Milton, of the U.S. Geological Survey, made a detailed geologic study of the island with particular reference to the nature and structure of the sedimentary rocks. The results of these studies are summarized in reports by Vedder and others (1956) and by Vedder, Norris, and Schoellhamer (written communication, 1957). Because their studies were primarily for petroleum exploration, they did not consider the water-bearing character of the deposits in detail. However, advance copies of their map and data were supplied to the authors and were very useful in this ground-water study. In addition, Mr. Vedder made a special visit to the island during the early phases of the ground-water study for a field check and conference with the authors. This and other generous cooperation is gratefully acknowledged.

LOCATION, EXTENT, AND PHYSIOGRAPHIC FEATURES

San Nicolas Island is the outermost of the group of eight principal islands off the coast of southern California. The center of the island, at about lat 33°15′ N. and long 119°30′ W., is about 80 miles south of Santa Barbara and about 90 miles southwest of Los Angeles. (See index map, pl. 1.) The island is nearly symmetrically oval in shape—the long axis trends approximately 25° north of west—virtually parallel to the trend of the mainland coast between Los Angeles and Santa Barbara. The island is about 9 miles long, averages about 3 miles in width, and reaches a maximum width of 3.5 miles near the northwest end where it tapers sharply to a point. Its area is approximately 23 square miles. The island is occupied only by Naval installations, the main areas of occupation are on the 400- to 500-foot marine terraces along the northeast side of the island.

The island is a gently folded, intensely faulted elevated segment of the earth's crust whose highest point now stands 907 feet above mean sea level. The present island represents the part of an uplifted area that has survived active and rapidly progressing wave erosion of its margins. The dominant physiographic features of the island are several clearly defined wave-cut marine terraces which probably were formed during the Pleistocene epoch.

The lowest and most extensive of the principal terraces forms a narrow shelf about 100 feet above sea level around the east, north, and southwest margins of the island, and a broad, sand-covered plateau at the northwest end. The main island mass rises abruptly and steeply above this low platform to the upland surface. This upland surface slopes gently northward from the main drainage divide near the south side of the island at an average of about 4°, and is steepest between the 600- and 900-foot altitudes. From the divide southward, the main part of the island falls away steeply to narrow sandy and rocky beaches. The steep southern part, an eroded escarpment formed by extensive faulting, has an average slope of about 10° but locally slopes more than 45° near the canyon heads. Slopes between the upland surface and the low terrace platform average about 15°, flattening abruptly at the head of the terrace.

As many as 15 to 20 terrace levels may be discerned on the island, and detailed mapping on the basis of more precise altitude control might reveal more terrace levels. The terraces form isolated flat areas on ridges around the island margins and alternating staircaselike platforms separated by steep slopes on the upland area. Because of the steepness of the southern slope of the island, the wave-cut terraces are lacking or only poorly developed on that side. The terrace platforms slope gently seaward, as does the offshore platform presently being developed.

Where the terrace form is preserved it is mantled by thin, discontinuous deposits of gravel and sand resulting from wave action, by alluvial slope-wash material from higher levels, and by soil formed from weathering of the exposed rocks since the island was elevated. Wind action has built large and extensive sand dunes on the low terrace in the northern and northwestern parts of the island. These dunes form long ridges; they slope between the low terrace and the upland area and spread southeastward over the west end of the upland.

The main drainage divide lies close to the edge of the southern escarpment of the island. The stream courses along the north side head in steep-walled gullies on the steep slope near the divide, spread out in ill-defined, shallow channels on the flat terrace surfaces, and then plunge down the intervening slopes between the upper and lower terraces in very narrow, deep, steep-walled gullies and canyons. Many of these streams converge in the north-central and western parts of the island and cross the steep escarpment to the lower terrace in canyons as much as 200 feet deep. Along the north shore, from the base of the escarpment to the sea, the channels are steep sided and are 10 to 30 feet deep. In the dune areas to the west no surface drainage has developed. The drainage from the upland areas discharges into depressions between the dunes and is absorbed or evaporated. The steep southern slope is drained by very deep, V-shaped canyons which head in nearly vertical walls immediately beneath the main divide and are separated by knife-sharp rocky ridges.

Except during periods of precipitation, all but two of the stream courses on the island are dry and are characterized by dry cataracts and falls in the steeper segments. Where the gradient is flatter the courses are underlain by thin deposits of sand or rubbly gravel. There are a few brackish seeps along principal fault lines, especially on the south side. Tule Creek heads in steep gullies on the highest part of the island but loses most of its identity as a surface stream across an area of dunes, then continues northward in steep-sided gullies which join and become a deep canyon across the northern escarpment of the island. Dune sand has buried the channel of the creek below the scarp. A small perennial stream occupies the channel of Tule Creek throughout the main gully and canyon and is one of the main sources of water supply for the island. Also, in one steep canyon cutting across the western escarpment, small seepage springs maintain a small perennial flow for a short distance, but this flow is not utilized for a water supply.

The deepest canyons are on the south side of the island and near the central part. The extreme geologic youthfulness of the canyons is indicated by the irregularity of their long profiles and by an almost complete lack of integrated drainage patterns—each stream pursues an almost straight course down the slope and has only minor tributaries, or no tributaries at all.

649979—63——2

The topographic profile of the island is asymmetrical, whether viewed parallel to or normal to the longitudinal axis. If viewed from the northeast, as approached from the mainland, the island appears as a low platform at the west end, which rises steeply to the highest point, then gradually slopes southeastward, and falls away sharply to the sea at the east end. Viewed from the southeast, it appears as a flat, narrow, low platform on the north side, which rises sharply to the upper-terrace levels and then more gradually to the summit near the south side, and falls away steeply to the sea. Submarine contours shown on U.S. Coast and Geodetic chart 5113 show that to the south the steepness generally continues offshore, whereas the sea floor to the north and east is flat and slopes very gradually seaward. Shallow, rocky reefs occur for a long distance northwestward from the island.

GENERAL GEOLOGY

GEOLOGIC UNITS

The major part of San Nicolas Island is composed of marine sedimentary rocks consisting of conglomerate, sandstone, siltstone, and shale. Thin dikes of diabase intrude these rocks near the southeast end of the island. Overlying these older consolidated rocks are minor veneers of marine-terrace and alluvial slope-wash deposits and superficial to massive deposits of windblown sand. Because the principal purpose of this investigation was to determine the potential water-yielding areas and deposits of the island, the rocks and deposits are grouped and classified on the basis of water-yielding character into three geologic units, whose areal distribution is shown on the geologic map and whose thickness and subsurface relations are shown on two geologic sections (pl. 1).

These units are (1) consolidated marine sediments locally intruded by diabase dikes, (2) marine terrace and alluvial slope-wash deposits, and (3) windblown sand. The last unit is further subdivided into four subunits on the basis of lithologic, absorptive, and water-yielding characteristics, which in general bear little or no relation to stratigraphic position or time of deposition. These subunits are (1) active dune sand; (2) vegetated, friable, fresh sand not now in transport; (3) indurated, compacted, uncemented sand now being eroded by the wind; this subunit usually underlies (1) and (2); and (4) cemented, weathered, highly eroded sand, usually underlying the other three units.

The principal geologic contacts and structural features shown on the geologic map are taken from preliminary copies of field maps prepared in 1955–56 by the Geological Survey as a part of an investigation for the Director of the Office of Naval Petroleum Reserves

(Vedder, Norris, and Schoellhamer, written communication, 1957). Locally the contacts and structure shown on the preliminary maps were modified, and the windblown sand was subdivided, as shown on plate 1, by the present authors. Study of microfossils collected in the 1955–56 investigation showed that the marine sedimentary rocks that make up the bulk of the island are of Eocene age, possibly late Eocene (J. G. Vedder, oral communication, 1957). The diabase dikes that intrude these rocks are therefore younger and are possibly associated with the extensive intrusive activity that took place on the mainland during Miocene time. All the surficial deposits are believed to be late Pleistocene and Recent in age. Fragmental megafossils collected from deposits of the 400- and 500-foot terraces are all of that age range; nearly all are represented by living species. The principal geologic units are discussed briefly in order from oldest to youngest on the following pages. The sand subunits are discussed in greater detail.

MARINE SEDIMENTARY ROCKS AND INTRUSIVE DIKES

The marine sedimentary rocks, which compose the major part of San Nicolas Island and the surrounding sea floor, were mapped in detail by the Geological Survey in 1955–56. This mapping shows that most of the island is composed of coarse to very fine marine sedimentary rocks that comprise 30 units. Two of the units contain basal cobble-bearing siltstone and one unit contains a conglomerate composed of coarse siliceous clasts of intrusive and extrusive rocks in a sand and silt matrix. These beds are overlain by a thick series of thick-bedded sandstone separated by thin beds of siltstone or mudstone, and a thick series of siltstone or shale and minor thin beds of sandstone. The remainder of the units repeat this sequence, except that the cobble beds and conglomerate are absent. The beds are broadly folded and extensively faulted. The fold axis lies near, and nearly parallels, the south coast so that the beds in general dip southwestward along the south shore and northeastward throughout the rest of the island. Abundant foraminifers and mollusks indicate deposition of the beds during the Eocene epoch in sea water of shallow to moderate depth. The thickness of these sediments was not determined, and it is not known what underlies the exposed section.

Minor intrusive bodies of andesite diabase and olivine diabase occur as dikes that cut across the sedimentary rocks and are exposed along the margins of the island. These rocks are thought to be associated with similar rocks of probable Miocene age on the mainland and were intruded into joints in the sedimentary rocks. They are grouped herein with the sedimentary rocks and are shown on the geologic map and sections as marine sedimentary rocks and intrusive dikes, undifferentiated (pl. 1).

Outcrop samples of the marine sedimentary rocks, collected and tested in the 1955–56 study had very low permeabilities; specific yield ranged from about 11 to 28 percent. Field inspection shows that the rocks are generally massive, intensively fractured but only to shallow depth, cut by numerous faults, and moderately but shallowly weathered. In general, they cannot be expected to transmit or yield appreciable quantities of water to wells. That these beds do contain some ground water is evident from several small seeps that emerge along bedding planes and fault lines at low altitudes on the north and south slopes. This water, however, is highly saline and unusable for domestic purposes. An analysis of water taken from one such seep on the south coast is given in the section on chemical quality of water. In general, ground water does not penetrate deeply into these rocks but moves downslope toward the sea along the contact with overlying deposits or within the shallow weathered zone.

MARINE TERRACE DEPOSITS

A thin veneer of well-weathered clayey poorly sorted sandy gravel and slope-wash debris mantles the marine terraces and the gentler intervening slopes. These deposits are dominantly shoreline deposits spread across the wave-cut platforms by the receding sea; in part they are alluvial materials deposited by subsequent slope wash from upland areas. The deposits range from 1 to 5 feet in thickness and rarely exceed 10 feet. Evidence of resubmergence or alternate emergence and submergence was not observed on the island. It is therefore assumed that the island has emerged continuously and that the thin veneer of shoreline deposits originally was nearly continuous over the island. Postemergence terrestrial erosion has removed this veneer from the steeper slopes and has redeposited some of the material on the gentler slopes. The deposits on the gentler slopes probably are nearly continuous beneath the windblown sand, separating it from the marine sedimentary rocks. Except beneath the sand deposits, the thin marine-terrace unit is everywhere above the zone of saturation and has no potential as a water-yielding deposit. Where it lies beneath saturated sand, however, it is believed to form an important part of the permeable storage unit for potable water, which percolates vertically downward through the sand, then laterally along the bedrock surface through the veneer of terrace materials. The rising water in Tule Creek and along the western escarpment occurs at the contact between the terrace deposits or overlying sand and the bedrock surface.

WINDBLOWN SAND

The windblown sand consists of extensive masses of well-sorted uncemented to well-cemented medium to coarse sand covering the major part of the west end of the island and forming large dunes along the northern margin. Deposition of some of the sand may have been contemporaneous with the formation of the 100-foot terrace or higher terraces; thus the deposits probably range in age from late Pleistocene to Recent. Similar terrace levels along the coast of Santa Barbara County have been assigned a late Pleistocene age by Upson (1951).

The sand is derived principally from wave and current erosion of the older marine sedimentary rocks which form the sea floor around the island. After being washed onto the beaches, the sand is retransported by strong prevailing northwest winds and deposited as dunes and thin coatings and stringers. The sand grains include quartz, feldspar, garnet, ferruginous minerals, and fragments of fine-textured mafic rocks. Molluscan shell fragments and the tests of foraminifers are abundant in some of the deposits. The feldspar, ferruginous minerals, and calcareous shell materials are weathered and altered in older deposits, forming clayey reddish weathered zones.

Calcium carbonate, occurring as thin plates, stringers, and lenticular or irregular masses of gray-white caliche, cements many of the sand deposits. The zone of cementation extends from the shoreline to the highest point inland, and includes all the sand deposits except the active dunes. The older deposits on the heights are the most completely cemented and contain at least two cemented zones as much as 8 to 10 feet thick, separated by compacted, virtually uncemented zones of comparable thickness. These older deposits are best exposed in deep gullies. Locally, miniature "forests" of carbonate-cemented sand tubes, ranging in diameter from a few millimeters to 6 inches and in length from a few inches to several feet, stand on the surface of eroded dune areas. These tubes are formed by cementation that takes place where water seeps radially outward from channels left by decaying roots, buried stems, and burrowing insects or animals.

The windblown sand is believed to attain its maximum thickness of about 125 feet at the base of the westward-facing escarpment. On the uplands it ranges in thickness from 0 to 50 or 75 feet, and it averages about 50 feet in thickness on the low platform at the west end of the island. Large topographic irregularities on the buried bedrock surface cause large variations in thickness of the sand within short distances.

The sand ranges from highly permeable and absorptive to virtually impermeable, according to the degree of weathering and cementation. It is subdivided into four subunits on the basis of the estimated absorptive and water-yielding characteristics.

CEMENTED DUNE SAND

Underlying most of the other sand subunits and forming extensive exposures from the northwest beaches to the highest hill is a thick unit of windblown sand which contains thick zones of calcium carbonate cement in the form of gray-white caliche. This subunit is thickest and most extensive along and adjacent to the westward-facing escarpment overlooking the western terrace platform. It is best exposed in cross section in the heads of the very steep gullies and canyons cut across the western escarpment, where it contains crossbedded medium to very coarse windblown sand which is highly cemented by caliche in at least 2 zones up to 8 or 10 feet thick. These zones are separated by equally thick indurated but poorly cemented sand. Also contained within the unit are thin, discontinuous beds of slope-wash debris interbedded with the dune deposits. The subunit is exposed in large areas around the northwestern slope of the highest hills and extends down the principal long ridge between the upland and the northwestern beaches. Runoff and wind erosion have etched the surface, leaving broad areas of rough, scabby, impervious, and unvegetated caliche.

Auger holes, bored by the authors in uncemented sand deposits in many locations throughout the sand-covered part of the island, usually penetrated a caliche-cemented subunit at varying depths. However, the same type of cementation occurs in the weathered zone of the underlying marine sedimentary rocks, and this zone is usually indistinguishable in auger cuttings from the cemented dune sand. It is not known, therefore, how extensive the cemented-sand subunit is beneath the other sand subunits.

In general, this subunit represents the earliest and oldest dune-sand accumulations on the island, possibly late Pleistocene in age, and much of it on the upland and the western escarpment probably accumulated during the period when sea level was about 100 to 200 feet higher than at present and when the broad lower terrace was being cut (Upson, 1951). This interpretation is based mainly upon thick beds of coarse sand containing numerous well-preserved fragile foraminiferal tests, bits of seaweed and wood, and large, angular molluscan shell fragments in the basal part of the unit far inland from the present beaches. This same type of sand and included debris is being deposited now only on and adjacent to the present beaches.

The caliche cementation is believed to result mainly from solution of the constituent calcium carbonate shell fragments by downward-percolating rainwater. It then is concentrated by capillary rise to or near the surface and deposited as a cementing agent upon evaporation of the water. This is a constant, slow, and repetitious process, and the occurrence of alternating well-cemented and poorly cemented or uncemented deposits probably is related largely to variations in climate, the position of sand supply relative to a given area, and the immobility of a given deposit over a sufficient period of time to become cemented.

Because the caliche is discontinuously distributed throughout this subunit and because the subunit contains a large volume of virtually uncemented, highly premeable sand and is in direct contact with overlying highly absorptive sands over large areas, it is believed to be one of the most important ground-water-storing and water-yielding deposits on the island.

INDURATED DUNE SAND

Generally underlying large parts of the loose active and inactive dune sand and exposed extensively in areas of deflation, mainly on the upland, is a dark-gray to reddish-gray hard, indurated dune sand (pl. 1). Where best exposed in interdune areas south of the well field and northwest of Tule Creek, this subunit was observed to have a hard crust ranging in thickness from 6 to 18 inches. Very little cementation can be seen, and when thoroughly wetted the hard layer becomes a soft, clayey, very friable, somewhat weathered sand. The exposed areas of this subunit are generally very flat, gently sloping, and windswept.

During the short periods of relatively heavy precipitation, characteristic of the rainy season, water runs off from these areas as sheet flow to the surrounding dune areas or to stream channels. Immediately beneath the hard surface crust the sand of this subunit is soft, dry, and extremely friable, so that once the crust is breached the subunit may absorb water rapidly. Where gullies have been cut through the crust, wind erosion often excavates large caves or galleries until the weight of the overhanging shelf causes it to collapse. These collapsed structures are evident throughout the sand area and in many places are buried by more recent dunes. In the Tule Creek area this subunit is believed to range in thickness from a few inches to 50 feet and to be the principal deposit containing potable ground water in the area. It is not known whether this subunit is an important water-bearing deposit in the lower altitude dune-sand areas also.

VEGETATED DUNE SAND

The location of fresh, gray, loose dune sand which contains kitchen middens and has the same characteristics as the active dune sand, except that it is virtually immobilized by vegetative growth, is shown on plate 1. This subunit is of minor extent, the principal areas being near the eastern fringes of the sand area and in large patches along the north coast, east and west of Thousand Springs. Where present, this subunit readily absorbs and transmits precipitation and runoff to the base of the sand or to underlying deposits. Transpiration and direct evaporation from the relatively heavy vegetation on this subunit probably materially reduces the amount of water that reaches the ground-water body beneath.

ACTIVE DUNE SAND

Fresh, gray, loose, well-sorted sand being actively worked and subject to continual retransport and deposition by the nearly constant northwesterly winds is shown on plate 1 as active dune sand. This sand covers nearly all the low western terrace area to depths ranging from a few inches near the margins of the outcrop to several tens of feet in large dune areas. Near the strand line, this sand is derived directly from the beaches, but inland and especially on the upland areas the active dune sand is derived in part from deflation of older sand units and in part from erosion of the bedrock sandstone and siltstone. Many of the larger active dune areas contain large, thick accumulations of shells representing Indian kitchen middens. These sands are almost unvegetated, and although they are believed to be everywhere above the zone of saturation, they absorb practically all precipitation on or runoff to them. Because of this fact and because they cover such a large part of the total dune-sand area of the island, they serve a very important function in accepting, preserving from evaporation, and transmitting precipitation and runoff to the lower part of the sand and (or) to underlying water-bearing deposits. Approximately three-fourths of the total sand area is covered by active dune sand.

GEOLOGIC STRUCTURE

Detailed geologic mapping by the Geological Survey in 1955–56 showed that San Nicolas Island is mainly an uplifted segment of the northeast limb of a southeastward-plunging anticlinal fold. The fold axis trends about N. 60° W. Offshore mapping along the fold axis toward the northwest, by geologists using underwater-breathing apparatus, showed some flattening of the plunge but is believed not to have shown conclusive closure which would indicate a dome. The fold axis is intersected at about 45° by a series of westward-trending faults, and numerous northwestward- and northeastward-trending faults cut across this principal fault trend, giving the island a blocky structure. All the principal faults and most of the significant minor faults are shown on the geologic map and are taken from the preliminary map of Vedder, Norris, and Schoellhamer (written communication, 1957).

Because of the regional folding the stratified marine sedimentary rocks dip toward the northeast on the north side and toward the southeast on the south side of the fold axis. North of the fold axis the dip ranges from about 5° to 25° and averages about 12° to 15°. South of the fold axis the dip averages about 15°. Local faulting causes large deviations in strike and dip from the regional trends.

The direction of relative movement along the westward-trending faults is mainly up on the north, accounting for a large part of the elevation of the island. Along the northeastward- and northwestward-trending faults the movement is generally up on the east, so that lower stratigraphic units are repeatedly uplifted and exposed as one goes eastward along the south margin of the island. The very straight traces of both sets of faults across very irregular topography indicate that the fault planes are very steep, as is apparent in every place where the fault planes are exposed. Wherever determinable, the movement appears to have been almost vertical, there having been little or no horizontal component of movement. Vertical displacement on the major faults ranges from a few tens of feet to 800 feet (Vedder, Norris, and Schoellhamer, written communication, 1957). Lesser displacements occur on the minor faults. Offshore structural features were not considered.

The importance of these structural features to the water-supply potential of the island is threefold:

1. Wave erosion during emergence accentuated the steep southern slope along the weaker of the westward-trending faults and was less competent in cutting away the gently dipping beds on the north side. This appears to be because the seaward (south) side receives the brunt of the erosional forces of the Pacific Ocean. This differential erosion resulted in a drainage divide near the south side of the island, which in turn produced relatively large catchment and drainage areas on the northern upland areas and provides maximum opportunity for ground-water recharge on the north slopes.

2. Uplift and northeastward tilting of weak silty and shaly beds permitted development of the large marine terrace at the west end of the island. Sand that accumulated on the terrace forms a large absorptive area and forms a potentially important ground-water storage unit.

3. The upturned, eroded edges of the beds provide maximum opportunity for downdip percolation of potentially recoverable potable water from surface streams and blanketing dune sand into the marine sediments, which originally were saturated with sea water. Because the permeability of the upturned beds is very low, however, the greater part of the small quantity of ground water that infiltrates escapes by way of bedding-plane openings and fractures. These

649979—63——3

openings become fewer and less open with depth, and it is believed that nearly all such percolating waters move downdip only a few feet or tens of feet, then laterally toward points of discharge, such as a bedrock seepage spring. These springs usually appear near the shoreline a few feet below the contact with overlying sand or terrace deposits, as is illustrated by the numerous bedrock seeps and springs in the Thousand Springs area.

GROUND-WATER FEATURES

OCCURRENCE

Small springs and seeps of fresh to brackish water are mentioned in some early references to the island as occurring near Brooks Landing in Army Cove, in Corral Harbor, near the presently designated Thousand Springs area, and about a mile inland in Tule Creek. To meet the needs incident to the establishment of the Navy facility on the island, the surface flow of Tule Creek was diverted for use and four wells were drilled in the flat dune-sand area near the midreaches of Tule Creek just upslope and south of the rising-water area (pl. 1). The wells yielded small quantities of fresh water from either the base of the sand deposits or from the thin weathered zone at the top of the consolidated marine sediments. The drillers' logs of these wells are given in table 1.

The present investigation showed that the island is composed almost entirely of consolidated, virtually impermeable marine sedimentary rocks which nearly everywhere crop out well above mean sea level. Fractures and separations along bedding planes in these rocks provide some permeability, however, and theoretically a lens of relatively fresh water, derived from precipitation, may exist at or near sea level within the island. According to a principle first applied to hydrology by the Dutch engineer W. Badon-Ghyben (1899) and also stated independently a few years later by Alexander Herzberg (1901) in Germany, the postulated lens of fresh water would float on the underlying sea water. However, on San Nicolas Island in every area where ground water was observed seeping from openings in the consolidated sedimentary rocks it was too salty for human consumption. Therefore, it is probable that ground water at or near sea level within the island has acquired sufficient salt from the sedimentary rocks or by mixing with sea water to make it unpotable. Therefore, exploration for a supply in the areas in which these rocks are exposed is not promising.

The nearly impermeable marine sediments and the very thin discontinuous mantle of clayey terrace deposits provide little or no storage capacity for recoverable quantities of potable ground water.

TABLE 1.—*Drillers' logs of four supply wells in the Tule Creek drainage area*

[Drilled by Lynn Hall about 1950 or 1951]

Well 1 (Navy C)

[In Tule Creek area. Altitude about 589 feet. Twelve-inch casing in 18-in. hole, cable-tool drilled. Standing water level 23 ft below land surface when drilled. Reported to yield 10 gpm when drilled. Water level, 10/29/56, 22.9 ft below land surface; yield reported by Navy, about 4 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Dune sand:			Water at 47 ft.		
Yellow sandstone	2	2	Terrace deposit and (or) weathered bedrock:		
Yellow clay	23	25			
White sand	5	30	Blue clay	20	67
Yellow clay	17	47			

Well 2 (Navy D)

[In Tule Creek area. Altitude about 571 ft. Twelve-inch casing in 18-in. hole, cable-tool drilled. Reported to yield 8 gals in 28 secs (17 gpm) when drilled. Water level, 10/29/56, 32.2 ft below land surface; yield reported by Navy, about 7.5 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Dune sand:			Water at 54 ft.		
Surface sand	5	5	Terrace deposit and (or) weathered bedrock:		
Sand	7	12			
Yellow sand	42	54	Blue clay	18	72

Well 3 (Navy E)

[In Tule Creek area. Altitude about 572 ft. Twelve-inch casing in 18-inch hole, cable-tool drilled. Standing water level 39 ft below land surface when drilled. Reported to yield 9 gals in 28 secs (19 gpm) when drilled. Water level, 10/29/56, 36.5 ft below land surface; yield reported by Navy, about 9 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Dune sand:			Water at 71 ft.		
Surface sand	5	5	Terrace deposit and (or) weathered bedrock:		
Sand	10	15			
Yellow clay	45	60	Blue clay	10	80
Yellow clay and blue clay	10	70			

Well 4 (Navy B)

[In Tule Creek area. Altitude about 569 ft. Twelve-inch casing in 18-in. hole, cable-tool drilled. Standing water level 32 ft below land surface when drilled. Reported to yield 8 gpm when drilled. Water level, 10/29/56, 33.0 ft below land surface; yield reported by Navy, about 7 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Dune sand:			Terrace deposit and (or) weathered bedrock:		
Surface sand and clay	8	8			
Sand	7	15	Blue clay	18	68
Yellow clay	35	50	Sandstone	2	70
Water at 50 ft.			Hole plugged to 60 ft.		

Therefore, only that part of the west end of the island which is covered by a significant thickness and areal extent of windblown sand affords the conditions necessary to the occurrence of usable quantities of ground water. There are two principal areas of sand accumulation on the west end of the island in which potable ground water may occur in significant and potentially recoverable quantities. These are shown crosshatched on the geologic map (pl. 1).

The more favorable of these two areas for water-supply exploration is on the upland near Tule Creek. The area is easily accessible, is at a high altitude, and is closer to areas of water need and use. As shown by the geologic map and section (pl. 1), the area contains a large volume of permeable sand, probably as much as 75 feet in maximum thickness. Data from the drillers', logs (table 1) suggests that ground water occurs as a perched or semiperched water body in the basal part of the sand and in the upper few feet of weathered marine sedimentary rocks. Chemical analyses of samples of water obtained from existing wells and from rising water in Tule Creek show the water to be of marginal quality for human consumption, containing principally sodium chloride in solution (table 3).

The second area in which ground water may occur in potentially recoverable quantities is at the northern margin of the low western terrace. At this locality the geologic map and section (pl. 1) suggests that a large area underlain by a thick section of windblown sand extends to the beach, where numerous fresh-water springs and seeps appear at or just above the tidal zone. The geologic and hydrologic features suggest that a perched water body of substantial size may be present in the basal part of the sand.

SOURCE AND MOVEMENT

Precipitation upon the island is the only source of the fresh ground water on San Nicolas Island. At places in the channel between San Nicolas Island and the mainland the ocean is more than 6,000 feet deep, and the channel bottom is about 1,200 feet deep at its shallowest known point. There is no evidence of any geologic structure that would permit fresh water to move between the mainland and the island. The ground-water bodies are recharged by deep penetration of rain and runoff into the highly absorptive fresh dune sand.

The ground water on San Nicolas Island percolates from points of higher head to points of lower head in response to gravity. There is no evidence to suggest the occurrence of hot springs or that water rises in response to pressures from remote sources or from the earth's interior. Water moves downward to the main water table or to an impermeable zone which diverts the water laterally downslope. Throughout all the island east of the dune-sand area, the small part of the precipitation that percolates into the very thin soil and marine terrace mantle enters fractures or bedding-plane openings in the marine sediments or is diverted laterally along the bedrock surface to discharge as short-lived seeps in the gullies.

In the areas of highly permeable dune sand, rainwater and runoff from cemented sand or marine sediments is readily absorbed and percolates vertically to less permeable zones of weathering, cementation, or dipping bedrock, then moves laterally downslope. The largest part of this water moves slowly through the basal part of the sand deposits and immediately underlying weathered bedrock. In the Tule Creek area this movement is in general in the same direction as the surface drainage, except that the northeastward dip of the underlying sediments tends to cause percolating water to move toward the eastern and Tule Creek parts of the dune-sand area. Probably nearly all water percolating into the dune sand on the upland south of a line between the present Tule Creek diversion point and the point called North Head (pl. 1) and north of the main road to the west end of the island is tributary to the Tule Creek water-yielding area as shown.

Water percolating into the sand on the upland at the west end of the island moves northwestward along the contact between the sand and the underlying marine sediments and appears in springs in the deep canyons which cut the escarpment overlooking the low western platform. That part of the spring flow that is not evaporated or transpired percolates into active dunes downslope and moves westward into the active sand-dune area. It is believed that, because of the gentle northward slope of the wave-cut surface of the northern three-fourths of the low western dune-covered marine platform and because of the general northeastward dip of the underlying sediments in this area, virtually all the water that percolates into the overlying sand moves northwestward toward the designated potential water-bearing area. The lack of fresh-water springs along the south edge of the island and numerous fresh-water springs and seeps along the edge of the island between Viscaino Point and Corral Harbor tends to strengthen this interpretation.

The fresh water that seeps in small amounts into the marine sedimentary basement rocks percolates very slowly through small fracture or bedding-plane channels, acquiring salt by solution of solid material or by mixing with salt water.

Because of decreasing size and number of openings and consequent decreasing permeability of these rocks with depth, this small quantity of water generally is believed to remain near the surface, most of it reappearing in small springs and seeps of highly saline water in the larger canyons and along barriers caused by faults.

Twelve perennial springs or seeps are shown on plate 1. Several localities were found where intermittent seeps or small springs may appear during or soon after periods of heavy rainfall and recharge; they are mostly along the south-coast slopes, but because they are not considered to be potential sources of water supply for the Navy, they were not described. Table 2 gives the pertinent data for the 12 springs shown on plate 1.

CHEMICAL QUALITY OF WATER

The ground water already developed on San Nicolas Island is marginal or inferior in quality as judged by standards for use on interstate carriers (U.S. Public Health Service, 1946). These

TABLE 2.—*Descriptions of 12 perennial springs and seeps on San Nicolas Island, October 1956*

Number on pl. 1	Altitude above mean sea level[1] (ft)	Approximate yield (gpm)	Use	Remarks (geologic symbols shown on pl. 1)
1	550	0.5	Unused	Water seeps into alluvium in canyon bottom or into sandstone bed in weathered bedrock. Flow contributes to spring 3 downstream. Potable.
2	20	.5	do	Brackish seep along bedding planes in bedrock. Rises in gully bottom seaward of road in Army Cove. Not potable.
3	465	10	Domestic	Rising water in Tule Creek. Flows to collection box and is used for domestic supply. Potable; chemical analysis in table 3.
4	500	2	Unused	Rises at Qsc-Tu contact where exposed on western scarp east of road, flows under road. Potable; chemical analysis in table 3.
5	500	1	do	Rises at Qsc-Tu contact SE. of road in deep canyon on western scarp. Just south of spring 4. Potable.
6	500	.5	do	Rises at Qsc-Tu contact south of road in canyon south of spring 5 on western scarp. Potable.
7	25–30	3–5	do	Many springs and seeps appear at bedding planes and joints in Tu just beneath Qsc and Qt in the sea cliff and gully sides in this, the Thousand Springs area. Potable; chemical analysis of larger springs in table 3.
8	500	.5	do	Very brackish seep from joints in Tu in Canyon on south slope. Not potable.
9	50	2	do	Very brackish seeps from sandstone and shale along major fault zone near beach on south slope. Not potable; chemical analysis in table 3.
10	5	1	do	Numerous seeps along bedding planes and joints just above high tide and just beneath Qsa-Tu contact in sand-dune area along north coast. Potable.
11	5	2–5	do	Large area of grass and moss around seepage spring rising at Qsa-Tu contact on north beach just above high tide. Potable.
12	5	2	do	Fresh-water seeps along siltstone bed 5–10 ft below Qsa-Tu contact. Area to east along beach probably has fresh water moving seaward through beach sand and dune sand, which are in contact. Potable.

[1] Interpolated from U.S. Geologic Survey topographic maps.

standards indicate that in a water of good chemical quality the dissolved solids preferably should not exceed 500 ppm (parts per million), magnesium (Mg) 125 ppm, sulfate (SO_4) 250 ppm, and chloride (Cl) 250 ppm; fluoride (F) must not exceed 1.5 ppm. However, water containing 1,000 ppm of total solids is permissible where better water is not available. Such a dissolved-solids content is indicated by a specific conductance of about 1,500 micromhos at 25° C.

So far as is known, surface water running from the drainage areas on the island has not been analyzed, but in general the ground-water samples from sources nearest the areas where surface water recharges the sediments are of the best quality. Average chemical analyses of nine samples collected from each of the four wells, and of samples from four springs or rising-water areas, are shown in table 3. These analyses show that all are rather high in sodium chloride.

The analyses show that the well water from well 1, nearest the dune-recharge area has the lowest dissolved-solids content and is of the best quality. This water has a chloride content of 235 ppm and a

TABLE 3.—*Chemical analyses of ground water on San Nicolas Island*

[Analyzed by U.S. Geological Survey; data in parts per million]

Sample location	Well 1 (Navy C)	Well 2 (Navy D)	Well 3 (Navy E)	Well 4 (Navy B)	Spring 3	Spring 4 [1]	Spring 4 [2]	Spring 7	Spring 9	Sea Water [3]
Date of collection	Jan. 12, 1957	Jan. 12, 1957	Jan. 12, 1957	Jan. 12, 1957	Jan. 12, 1957	Jan. 12, 1957	Jan. 12, 1957	Jan. 12, 1957	Jan. 13, 1957	May 18, 1941
Calcium (Ca)	67	69	75	53	59	81	43	32	463	393
Magnesium (Mg)	25	29	38	20	29	14	13	16	459	1,228
Sodium (Na)	173	408	540	385	500	228	234	276	2,520	10,220
Potassium (K)	9.2	10	13	9.0	10	10	10	9.0	50	353
Bicarbonate (HCO_3)	296	427	356	388	452	484	363	308	369	139
Carbonate (CO_3)	0	0	18	0						
Sulfate (SO_4)	[4] 79	[4] 78	140	[4] 114	[4] 147	[4] 74	[4] 84	[4] 97	[4] 1,390	2,560
Chloride (Cl)	235	540	752	442	598	209	210	284	4,850	18,360
Fluoride (F)	.8	.4	.9	.8	.8	.4	.8	1.0	.4	
Nitrate (NO_3)			11							
Boron (B)	.18	.54	.49	.36	.49	.5	.52	.38	1.9	
Silica (SiO_2)			18							
Hardness as $CaCO_3$	269	293	342	213	268	260	160	144	3,040	6,030
Sum of determined constituents	735	1,340	1,780	1,220	1,570	855	774	867	9,920	[4] 33,200
Specific conductance (micromhos at 25° C)	1,320	2,420	3,110	2,170	2,740	1,480	1,390	1,540	15,300	
Percent sodium	56	74	77	79	79	64	75	79	64	77
pH	7.9	7.7	8.5	7.7	7.9	7.4	7.7	7.9	7.8	
Laboratory No.	21274	21275	21277	21278	21276	21279	21541	21280	21281	

[1] Stream, 20 ft from outlet.
[2] Stream, 100 ft from outlet.
[3] Analysis from Piper and Garrett (1953, p. 206) for comparison.
[4] Calculated.

specific conductance of 1,320 micromhos. The water from the other wells ranges in chloride concentration from 442 to 752 ppm and in conductance from 2,170 to 3,110 micromhos.

Of the samples taken from spring and rising-water sources, that from spring 4, on the escarpment along the main road to the west end of the island, has the best quality. This water has a chloride content of 210 ppm and a specific conductance of about 1,390 to 1,480 micromhos. The water from the Thousand Springs area, spring 7 nearly meets the minimum requirements of the standards for drinking water of the Public Health Service, whereas water from Tule Creek surface flow, spring 3 has a chloride concentration of 598 ppm and a specific conductance of 2,750 micromhos and is not potable. A sample from the largest seepage spring emerging from the marine sediments along the south shore, spring 9 contained 4,850 ppm of chloride and had a specific conductance of 15,300 micromhos. The water from these seeps is unsuitable for most uses. Although no analyses were made of water from the nearshore springs along the north shore, the taste indicated that the dissolved salts were less than in water from the wells or rising water in Tule Creek, and it is estimated that water in this area is similar to that in the Thousand Springs area.

RESULTS OF TEST DRILLING

On the basis of the hydrogeologic reconnaissance, nine test-well sites were selected. Of these nine sites, seven were drilled by the Roscoe Moss Co. with a cable-tool rig; of the seven wells drilled, two were pumped. After the drilling of seven wells and the testing of two, the program was discontinued because the results indicated that ground water could not be developed in the desired quantity of at least 5 gpm per well.

At test wells 1, 2, 5, and 6, ground water occurs in the consolidated rocks beneath the deposits of windblown sand at depths below the land surface of 40 to 50 feet; the sand deposits were unsaturated. Test wells 3, 7, and 9 yielded no water. Proposed test wells 4 and 8 were not drilled.

In addition to the test wells, a sump was constructed in the bed of Tule Creek about 500 feet south of test-well site 9. The sump, about 35 feet deep, was dug through the full thickness of the permeable deposits in the bed of the creek and draws water from sand deposited in the creekbed and from the cracks and fractures in the adjacent marine sedimentary rocks. The yield of the sump was tested by means of an automatic pump, which pumped the sump dry. After partial recovery of water level, the sump again was pumped dry. During a 42-day continuous test the sump yielded about 2,290 gpd (gallons per day) or about 1½ gpm.

The results of the test drilling indicate:

1. In the areas tested by wells, ground water is yielded in small quantities from cracks, fractures, and bedding planes in marine clay, shale, siltstone, and limestone, which underlie deposits of windblown sand. The overlying sand except in Tule Creek was unsaturated.

2. Pumping tests made at test wells 2 and 5 and at the sump in the bed of Tule Creek, indicate yields of about 1½ to 2 gpm.

3. Deeper wells probably would not yield ground water in quantities greater than 2 gpm because the fractures and bedding planes along which ground water moves are fewer and less open at greater depths. For example, the data from test well 6, drilled to a depth of 88 feet, show that water first was reached at about 45 feet; however, no additional water entered the well below about 50 feet.

4. The results of earlier studies and the test drilling indicate that further exploration for ground water probably is not warranted.

The test-well logs, water-level measurements, and yields of wells are given in tables 4 and 5.

TABLE 4.—*Logs and water-levels for test wells drilled in 1960*

Test well 1

[Drilled October 1960. Altitude about 515 ft. Water first occurred at about 50 ft. Well destroyed]

	Thickness (feet)	Depth (feet)
Sand, hard, indurated at surface.		
Sand, coarse, some fine, brown to yellowish-reddish-brown, subangular to subrounded, fair sorting (streaks of hard cemented sand and nodules of clay at about 10 ft)	35	35
Sand, coarse, some fine, brown (probably weathered zone)	3	38
Sand, coarse, some fine, brown, clayey	2	40
Clay, sandy, gray	4	44
Limestone, bluish-gray	5	49
Clay, bluish-gray, streaks of reddish-brown clay	7	56
Limestone, bluish-gray	5	61
Clay, yellowish-brown, small nodules of blue clay	1	62

Test well 2

[Drilled September 1960. Altitude about 565 ft; 8-in. casing from 0 to 52 ft, perforated from 35 to 51 ft; 24-in. casing from 0 to 18 ft. Water first reached at about 45 ft. Water level Oct. 2, 1960, 30.19 ft below land surface; water level Oct. 3, 1960, 30.16 ft below land surface]

	Thickness (feet)	Depth (feet)
Sand, hard, indurated at surface.		
Sand, medium to fine, yellowish-brown, subangular to subrounded, fair sorting	5	5
Sand, medium to fine, brown, subangular to subrounded, fair sorting, some clay	5	10
Clay, brown, some sand (weathered zone)	2	12
Sand, brown, fine to medium, mixed with clay	3	15
Clay, yellowish-brown, some reddish-brown, very hard drilling	24	39
Clay, blue	2	41
Clay, blue, yellowish-brown and brown, hard angular to subangular nodules of yellow clay	7	48
Clay, blue, dry nodules of blue clay	2	50
Siltstone, yellowish-greenish-brown	2	52

TABLE 4.—*Logs and water-levels for test wells drilled in 1960*—Continued

Test well 3

[Drilled October 1960. Altitude about 605 ft. Dry hole. Well destroyed]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand, fine to coarse, yellowish-brown, subangular to subrounded, fair sorting	9	9	Clay, yellowish-brown, white caliche, small nodules of blue clay, very hard drilling	3	23
Clay, yellowish-orangish-brown, some blue clay, weathered zone	9	18	Limestone, bluish-gray	8	31
Clay, blue, some yellowish-brown clay, some orangish-brown clay	2	20	Clay, yellowish-brown, some siltstone, nodules of blue clay	12	43
			Siltstone, yellowish-brown	1	44

Test well 5

[Drilled October 1960. Altitude about 85 ft. 8-inch casing from 0 to 47 ft, perforated from 36 to 46 ft; 24-inch casing from 0 to 24 ft. Water first occurred at about 40 ft. Water level Oct. 17, 1960, 33.87 ft below land surface; water level Oct. 18, 1960, 34.22 ft below land surface]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand, fine to coarse, yellowish-brown, subangular to subrounded	10	10	Clay, yellowish-brown, nodules of clay, at 34 ft nodules of limy sandstone as much as 2-in. size	12	35
Sand, fine to coarse, dark brown, silty, weathered	5	15	Sandstone, yellowish-brown limy	1	36
Clay	1	16	Clay, yellowish-brown	6	42
Sand, brown, clayey, nodules of clay	3	19	Clay, grayish-blue, nodules of yellowish-brown clay	1	43
Sand, clayey, white caliche	4	23	Limestone, grayish-blue	2	45
			Siltstone, yellowish-brown	2	47

Test well 6

[Drilled October 1960. Altitude about 95 ft. Water first occurred at about 45 ft, no additional water below about 50 ft. Well destroyed]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand, fine to coarse, brown, subangular to subrounded, indurated	2	2	Clay, bluish-gray, some yellowish-brown	1	33
Caliche zone	1	3	Clay, yellowish-brown	2	35
Sand, fine to coarse, whitish-gray, subangular to subrounded, silty	24	27	Clay, bluish-gray, some yellowish-brown	11	46
Limestone, bluish-gray; mixed with clay, gray and yellowish-brown; clay, bluish-gray, yellowish-brown, silty	5	32	Shale, bluish-gray; some clay	2	48
			Clay, bluish-gray	1	49
			Shale, bluish-gray	1	50
			Clay, bluish-gray	2	52
			Shale and clay	36	88

Test well 7

[Drilled November 1960. Altitude about 125 ft. Dry hole. Well destroyed]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand	30	30	Shale, blue	3	82
Sand, cemented	26	56	Clay, brown, some blue	3	85
Sand	8	64	Shale, blue	10	95
Sandstone, black rock	15	79			

Test well 9

[In Tule Creek area. Drilled November 1960. Altitude about 300 ft. Dry hole. Well destroyed]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand	18	18	Sandstone, yellowish-brown, weathered; probably cemented dune sand; mixed with sand, fine to medium, subrounded, not as well cemented	7	60
Sand, streaks of siltstone, some caliche, weathered	15	33	Clay, yellowish-brown, some bluish-gray	18	78
Clay, brown, silty	11	44	Clay, grayish-blue, some yellowish-brown	5	83
Sand, coarse, fair sorting; 50 percent caliche; fragments of small shells; some well-rounded pieces of shale, ¼- to 3-in. size; all subrounded	2	46	Sandstone, medium to fine, grayish-blue, top 3 in. yellowish-brown, very limy	5	88
Shale, yellowish-brown, hard drilling	2	48			
Clay, yellowish-brown; nodules of shale	5	53			

TABLE 5.—*Summary of development and pumping test, September 29 and 30, and October 17, 1960*

Test well 2

[Measuring point (Mp) is 1.83 ft above land-surface datum (Lsd)]

Time of observation	Production of well (gpm)	Depth to water (feet)		Remarks
		Mp	Lsd	
Sept. 29, 1960				
7:00 a.m.	----------	31. 84	30. 01	Not pumping.
8:53	----------	31. 86	30. 03	Pump column installed.
9:36	16	41. 50	39. 67	Pump started at 9:30 a.m.
9:44	----------	51. 06	49. 23	Breaking suction.
10:04	2	51. 96	50. 13	Water is dirty.
11:15	2	50. 47	48. 64	Water is cloudy.
11:35	2	50. 37	48. 54	Stopped pumping.
11:40	----------	49. 20	47. 37	Not pumping.
11:45	----------	47. 70	45. 87	Do.
11:50 a.m.	----------	47. 06	45. 23	Do.
12:05 p.m.	----------	45. 30	43. 47	Do.
12:10	----------	44. 36	42. 53	Do.
12:15	----------	43. 41	41. 58	Do.
12:25	----------	42. 56	40. 73	Do.
12:30	----------	41. 92	40. 09	Do.
12:40	----------	40. 98	39. 15	Do.
12:50	----------	39. 97	38. 14	Do.
1:00	----------	39. 12	37. 29	Do.
1:10	----------	38. 32	36. 49	Do.
1:20	----------	37. 60	35. 77	Do.
1:30	----------	36. 90	35. 07	Do.
1:40	----------	36. 35	34. 52	Began pumping.
1:47	18	40. 12	38. 29	Water dirty.
1:52	2	50. 35	48. 52	Do.
2:12	1½–2	50. 17	48. 34	
2:37	----------	--------	--------	Water is clearing.
2:45	----------	50. 15	48. 32	
3:00	1½–2	50. 30	48. 47	
3:05	----------	--------	--------	Turned off pump.
3:35	----------	45. 31	43. 48	Not pumping.
3:50	----------	43. 80	41. 97	Do.
3:55	1½	50. 41	48. 58	Began pumping.
4:30	1½	50. 39	48. 56	Stopped pumping.
Sept. 30, 1960				
7:10 a.m.	----------	32. 16	30. 33	Began pumping.
7:15	----------	--------	--------	Water cloudy.
7:29	10	43. 01	41. 18	
7:58	1	50. 58	48. 75	Water cloudy.
8:05	1½	51. 25	49. 42	
8:06	----------	--------	--------	Stopped pumping.

TABLE 5.—*Summary of development and pumping test, September 29 and 30, and October 17, 1960*

Test well 5

[Measuring point (Mp) is 2.0 ft above land-surface datum (Lsd)]

Time of observation	Production of well (gpm)	Depth to water (feet)		Remarks
		Mp	Lsd	
Oct. 17, 1960				
7:10 a.m	----------	35. 87	33. 87	Not pumping.
7:20	15	44. 92	42. 92	Pumping.
7:34	6	45. 96	43. 96	Do.
7:45	5	45. 87	43. 87	Do.
8:00	4	46. 01	44. 01	Do.
8:10	4	45. 91	43. 91	Do.
8:20	3½	46. 01	44. 01	Do.
8:29	----------	45. 10	43. 10	Not pumping.
8:35	----------	42. 04	40. 04	Do.
8:45	----------	40. 87	38. 87	Do.
8:55	----------	40. 17	38. 17	Do.
9:05	----------	39. 78	37. 78	Do.
9:15	----------	39. 51	37. 51	Do.
9:25	4½	45. 92	43. 92	Pumping.
9:35	3½	45. 85	43. 85	Do.
11:35	2½	45. 92	43. 92	Do.
12:01 p.m.	2½	45. 75	43. 75	Do.
12:17	2½	45. 97	43. 97	Do.
12:33	2½	45. 91	43. 91	Do.
1:00	2½	45. 92	43. 92	Do.
1:30	2	46. 05	44. 05	Do.
2:00	2	45. 64	43. 64	Do.
2:30	2	45. 75	43. 75	Do.
3:00	2	45. 88	43. 88	Do.
3:30	2	46. 08	44. 08	Do.
4:00	2	46. 01	44. 01	Do.
4:30	2	45. 86	43. 86	Do.
4:31	----------	--------	--------	Not pumping.

PRECIPITATION

Precipitation on San Nicolas Island is distinctly seasonal, with virtually all the rainfall occurring during the mild winter period from November through April. The winter period is followed by a warm dry summer. This pattern of precipitation and temperature distribution is the same as that of the coastal mainland of southern California. Climate of this nature is generally termed "Mediterranean" by climatologists.

The island's winter precipitation is closely associated with the polar Pacific air masses that originate over the Arctic sea and the interiors of Siberia and Alaska. These cold air masses are heated and moistened during their southeastward travel over the warmer waters of the North Pacific and reach the coast of southern California as a moist maritime air mass at the lower levels. As they move eastward over the mainland they are confronted by formidable mountain barriers. In passing these barriers the air masses are elevated and cooled, resulting in precipitation. Generally, the heaviest precipitation occurs at the higher altitudes; some mountain areas have an annual precipitation of more than 50 inches. In the coastal areas of the mainland the average annual precipitation is about 10 to 12 inches. The precipitation on San Nicolas Island is very similiar to that of these coastal areas because the small surface area and low relief of the island have little effect on the movement of the air masses.

Records of precipitation on San Nicolas Island have been obtained by the U.S. Navy since August 22, 1933, and except for the period October 1, 1946 to June 17, 1947, the record is continuous. The history of the rain-gage installation is as follows:

Aug. 22, 1933 to Aug. 23, 1944	Standard rain gage about midlength of island on north side, one-fourth mile from ocean, and at elevation 135 ft above mean sea level.
Sept. 9, 1940 to Aug. 23, 1944	Recording rain gage at same site.
Aug. 24, 1944 to Sept. 30, 1946	Standard and recording rain gages at Naval Auxiliary Air Station about 3 miles southeast of former site at elevation 500 ft above mean sea level. Discontinued Sept. 30, 1946.
June 18, 1947	Recording rain gage reestablished at Naval Auxiliary Air Station.

The base period for this study was selected as July 1933 to September 1955 at the time of the original analysis in 1957. As the purpose of this reconnaissance study is to furnish an estimate of the water resources of the island, the length of the base period used is not critical. The important considerations are that it be long enough to average out possible errors or misreadings in the precipitation data and that it be related to a long-term average. The base period July 1933 to September 1955 fulfills these criteria. Accordingly, it was decided not to change the base period to include more recent precipitation data.

A summary of monthly, annual, and seasonal precipitation on San Nicolas Island for the period July 1933 to September 1955 is given in table 6. These data were obtained from the climatological publications of the Weather Bureau and were used in this study. The annual summation is based on the water year beginning October 1 and

TABLE 6.—*Precipitation, in inches, on San Nicolas Island, July 1933 to September 1955*

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual [1]	Seasonal [2]
1933										[3] 0	T	0		
1934	0.36	0	2.08	0.80	1.75	0.13	0	T	0.09	0	0	.12	5.33	5.21
1935	.22	1.31	1.45	2.22	1.05	1.42	1.51	0	0	T	.15	0	9.33	9.30
1936	.16	.24	.90	.46	3.54	.30	.23	T	.13	T	1.11	T	7.07	6.11
1937	.35	.05	4.20	[4] 1.67	4.50	3.83	.05	0	0	0	0	0	14.65	15.76
1938	0	.10	2.75	.48	4.32	5.71	.25	.01	T	0	0	.31	13.93	13.62
1939	.48	.07	4.59	1.77	.54	.27	.23	0	0	0	0	1.50	9.45	8.26
1940	.11	.27	.55	3.43	4.17	.97	.62	0	0	0	0	0	10.12	11.62
1941	1.30	.52	5.66	3.88	4.64	4.42	1.17	0	0	0	0	0	21.59	21.59
1942	.86	.40	2.42	.17	1.31	.97	2.55	0	0	0	.10	0	8.78	8.68
1943	.73	0	.35	5.50	1.47	.80	.25	0	0	0	0	0	9.10	9.20
1944	.32	.45	3.00	1.74	3.37	.95	.98	T	T	T	0	0	10.81	10.81
1945	0	1.40	1.15	1.88	3.08	2.55	.02	T	.01	T	T	0	10.09	10.09
1946	.73	[4] .28	[4] 4.18	[4] .20	[4] .75	.87	.63	.04	T	0	0	0	7.68	7.68
1947	[3] .13	[3] 3.44	[3] 1.67	[3] .17	[3] .28	[3] .30	[3] .09	[3] 0	[3] .05	0	0	.04	6.17	6.13
1948	.16	.10	.61	0	.40	1.58	.49	0	0	0	0	0	3.34	3.38
1949	.14	0	[3] 1.10	[3] .63	.76	.91	.07	.25	.03	0	0	0	3.89	3.89
1950	.09	.56	2.04	1.21	1.25	.40	.54	.05	[3] .04	.09	.11	.20	6.58	6.18
1951	.39	1.39	.11	1.40	.78	.55	1.53	.02	.09	0	0	.02	6.28	6.66
1952	.12	.18	3.48	[3] 4.18	[3] .88	2.07	.74	.10	0	0	0	0	11.75	11.77
1953	0	[3] 1.34	[3] 2.24	1.27	[3] .12	[3] .57	.56	0	.05	0	0	.05	6.20	6.15
1954	0	[3] .93	.10	[4] 3.04	[4] .58	[4] 1.76	.34	.17	0	0	0	0	5.92	5.97
1955	0	.95	.81	1.71	.94	.41	.74	.30	0	0	0	0	5.86	5.86
Average													8.81	8.81

[1] Total for 12 months ending Sept. 30 of year shown in first column.
[2] Total for 12 months ending June 30 of year shown in first column.
[3] Wholly or partly estimated by Geological Survey.
[4] Estimated by U.S. Weather Bureau.

ending September 30. The seasonal summation is based on the climatological year beginning July 1 and ending June 30.

Precipitation for the period October 1, 1946 to June 17, 1947 was estimated on the basis of records obtained at Avalon (Santa Catalina Island), 60 miles east of San Nicolas Island. Some months of the years 1950, 1952, and 1953 required partial estimates (again, based on Avalon records) because of short periods of missing record. The Avalon record was chosen after a comparison of residual mass curves of monthly precipitation, based on the period October 1934 to September 1946, at San Nicolas Island, Avalon, and selected mainland locations.

The average precipitation at San Nicolas Island for the 22-year period 1933–55 is 8.81 inches per year and probably ranges from about 8 inches at or near mean sea level to about 10 inches at higher altitudes. The probable effect on the precipitation record by the change in location and altitude of the measuring site in 1944 was considered insignificant because of the small size of the island and the mild relief afforded by the topography.

The residual mass curves of figure 1 indicate that the series of generally wet years, 1937–45, was preceded by part of the series of generally dry years, 1917–36, and followed by the series of generally dry years, 1946–55; thus, the period of record comprises 9 predominantly wet years and 13 predominantly dry years. Troxell (1954) has shown that wet and dry periods in southern California are of unequal and varying length; the average wet period is 12.5 years long and the average dry period is 14.5 years long. Furthermore, these periods range in length from 4 to 43 years. On the basis of the criterion that a representative period for water resources study should include, at least, a wet period and a dry period in reasonable proportion to each other, the period of precipitation on San Nicolas Island, 1933–55, appears to be acceptable.

Further analysis of the 22-year period is necessary to determine if the combined wet-dry period of record is representative of a longer sequence of wet and dry periods. A comparison of the average seasonal precipitation for the 22-year base period 1933–55 with the generally accepted long-term averages for the 50-year period 1897–1947 at Avalon (adjusted) and, as a supporting example, Los Angeles, follows:

Location	*Average seasonal precipitation 1933–55 (inches)*	*Average seasonal precipitation 1897–1947 (inches)*	*Percent difference*
San Nicolas Island	8. 81	----------	----------
Avalon	12. 97	[1]12. 83	−1. 1
Los Angeles	15. 33	14. 81	−3. 4

[1] Bulletin No. 1, State Water Resources Board, Calif.

On the basis of the relatively small percentage differences between the averages for the 22-year base period and the 50-year averages at these

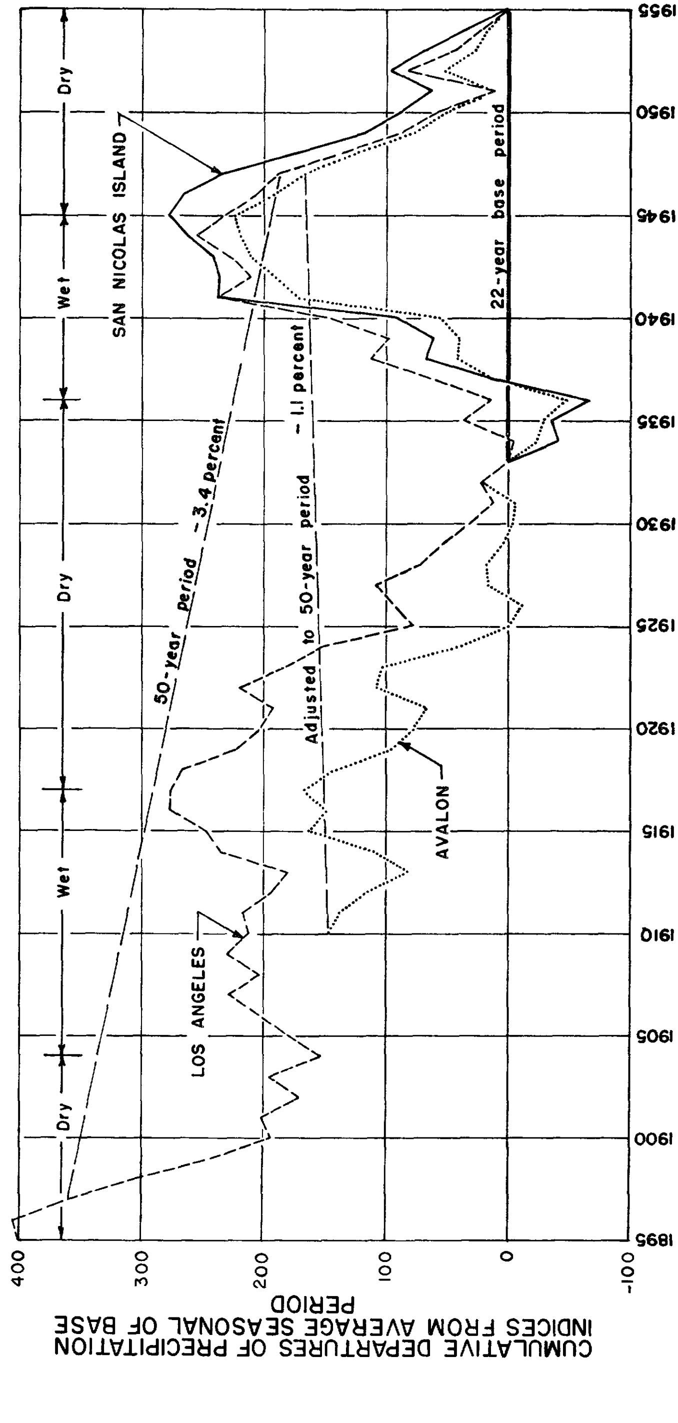

FIGURE 1.—Residual mass curves of seasonal precipitation indices, and deviation of long-time average seasonal precipitation from base period average.

locations and the similarity of the residual mass curves shown in figure 1, the 22-year period, 1933–55, is considered to be a representative period suitable for the water-supply study of this report.

The magnitude and distribution of the storm precipitation during this 22-year period are also considered to be representative of the long-time magnitude and distribution. The frequency diagram of figure 2 was prepared by utilizing the largest storm event of each year of the period. On the basis of the relationship indicated, a storm precipitation of 6.6 inches would have a recurrence interval of about once in 50 years. A storm precipitation of 4.4 inches would have a recurrence interval of about once in 10 years. The largest storm for the period was that of February 28 to March 3, 1938 when 5.48 inches was observed.

RECOVERABLE WATER

Recoverable water is defined as the part of precipitation that is available for man's use. It consists of direct runoff which passes relatively quickly to the nearest stream channel after each storm, and of water absorbed into the mantle rock, which penetrates below the root zone to become ground water. Thus, recoverable water is the residual after the natural water losses such as interception and evapotranspiration have been satisfied and after the soil-moisture deficiency in the root zones of the vegetative cover has been largely replenished.

The amount of recoverable water produced by a given amount of

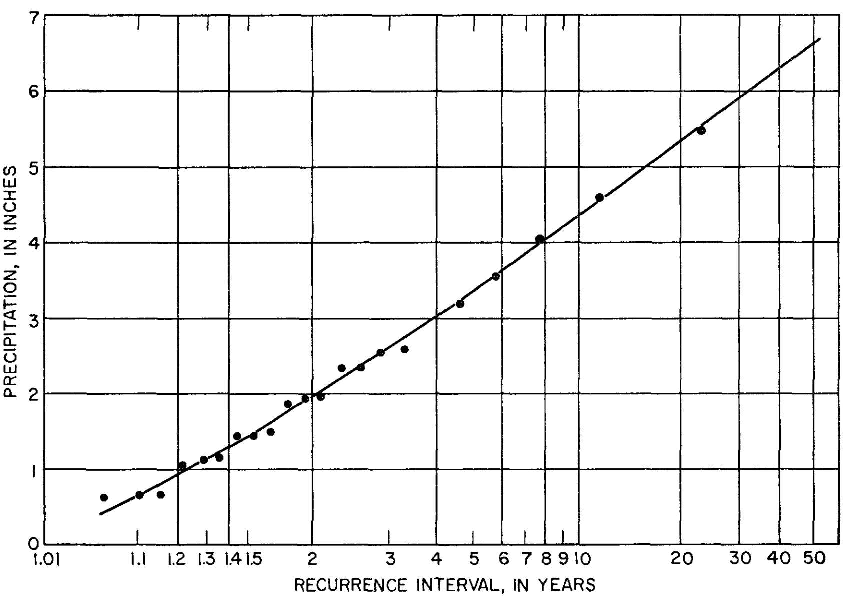

FIGURE 2.—Frequency of storm precipitation on San Nicolas Island, based on period 1933–55.

precipitation depends on the rate at which the precipitation occurs, and on the infiltration rate and moisture deficiency of the soil at the time of occurrence. As it is difficult to measure these variables and to evaluate them over a drainage area, the more reliable and direct course of action is to operate a stream-gaging station to measure the flow resulting from the integration of these and other factors. Streamflow data when combined with ground-water observations and analysis furnish a record of the amount of recoverable water.

Neither streamflow or observation well records, nor basic data on infiltration or soil moisture are available for San Nicolas Island. Thus, it is necessary to estimate the island's recoverable water from precipitation data by utilizing hydrologic relationships based on observational data collected on the mainland for areas having characteristics similar to those of San Nicolas Island.

TECHNIQUE OF RECOVERABLE-WATER ESTIMATE

The method used to estimate recoverable water in this report assumes that the initial loss of water resulting from each storm is that due to the interception and evaporation of rainfall from the foliage of the vegetative cover and the evaporation of rainfall stored in surface depressions on the ground during and after each rainfall event. On the basis of observational data obtained on the mainland (Blaney and others, 1930), this loss, termed "interception loss" in this report, is estimated to be 0.5 inch for storms of 1 to 10 inches and somewhat less than 0.5 inch for smaller storms. The other loss of water is that used to replenish the soil-moisture deficiency in the root zones of the vegetative cover. The magnitude of this loss for each storm is related to the moisture deficiency of the soil prior to the storm and to the size of the storm.

The influence of soil-moisture deficiency on the disposition of storm precipitation is shown on figure 3. This diagram indicates the relative magnitude of the interception loss, retention in the root zone, and recoverable water for varying amounts of storm precipitation. The interception loss plus the retention is termed "the natural water loss."

The retention curves for each value of soil-moisture deficiency reach a maximum and remain constant for values of storm precipitation greater than the amount needed to fully replenish the deficiency. The potential (maximum) natural-water loss occurs when both the retention and the interception loss are at a maximum. The shapes of the lower parts of the retention curves are based on the dimensionless curve of figure 4, which was prepared from observational data for mainland areas assumed to have hydrologic characteristics similar to those of San Nicolas Island.

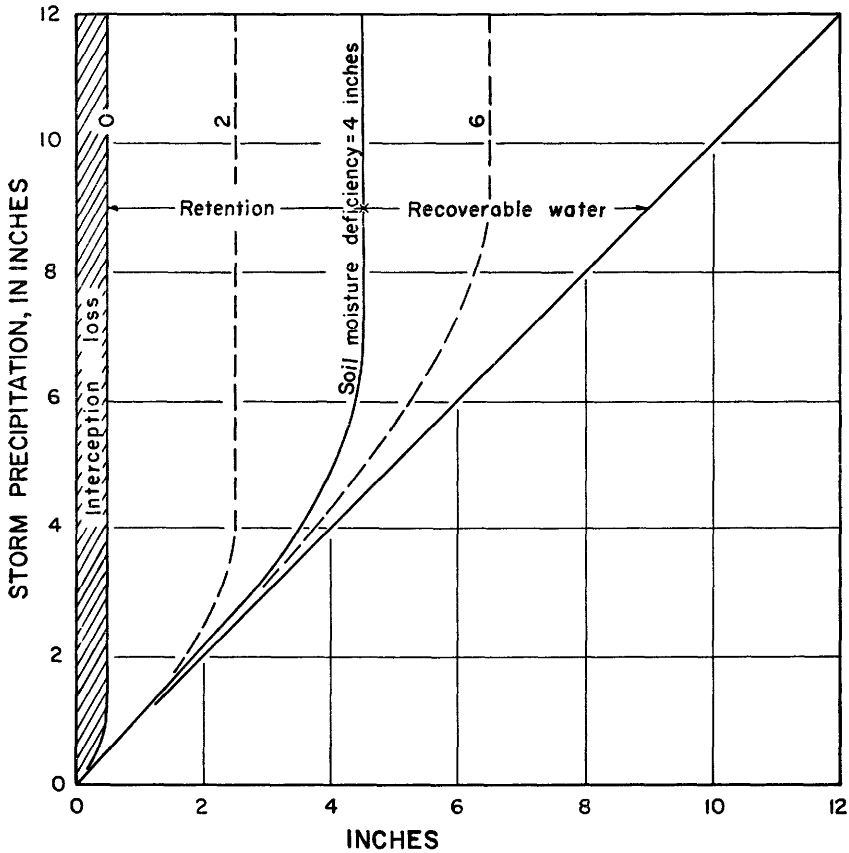

FIGURE 3.—Generalized diagram of the disposition of storm precipitation on San Nicolas Island.

Several contingent relationships developed by Troxell (1948) from available hydrologic data were used in preparing figure 4. The first, a relationship between mean seasonal precipitation and storm precipitation in valley-floor areas of southern California. From this relationship the storm precipitation was obtained for various recurrence intervals up to 100 years.

The second relationship, that between mean annual storm precipitation and mean annual maximum 5-day runoff, was used to obtain the mean annual maximum 5-day runoff. (For each storm, the maximum 5-day runoff is considered representative of the amount of recoverable water.) The mean annual storm precipitation was obtained directly from the records of precipitation on San Nicolas Island.

The maximum 5-day runoff at the same recurrence intervals used for storm precipitation was obtained from the third relationship, which relates the maximum 5-day runoff to the mean annual maximum 5-day runoff for various recurrence intervals.

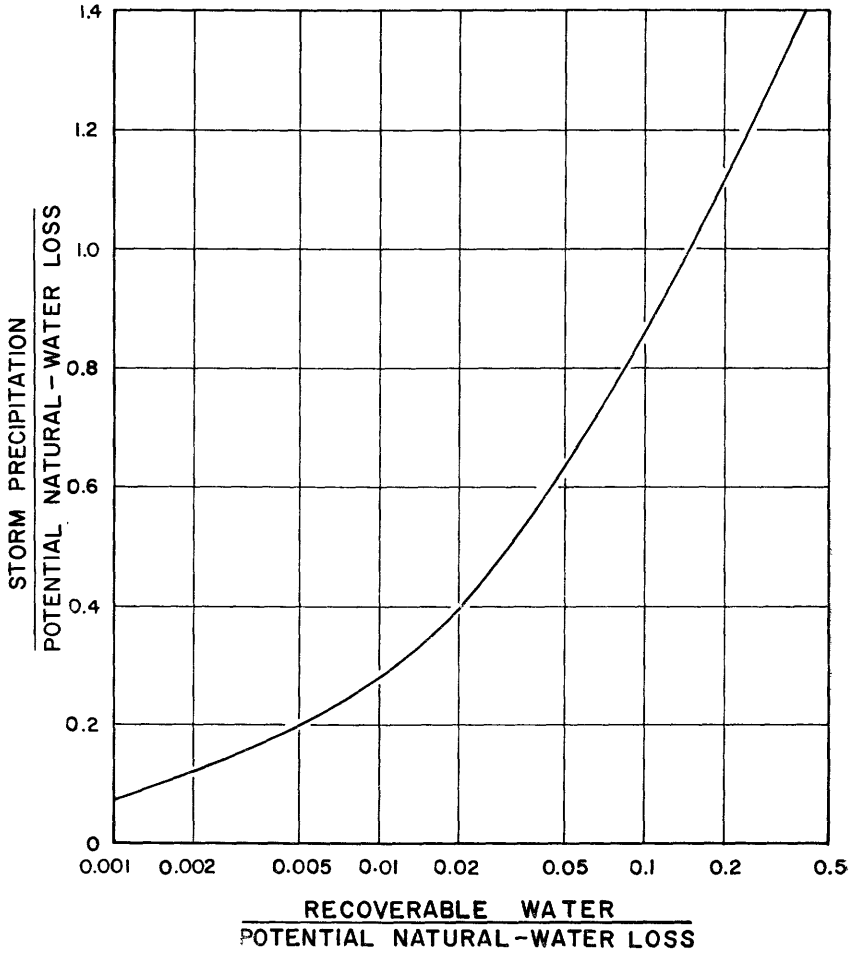

FIGURE 4.—Relationship between storm precipitation, recoverable water, and potential natural-water loss, based on mainland areas in southern California.

For any given frequency, the difference between the storm precipitation and the maximum 5-day runoff was considered to be the natural water loss. The difference reached a maximum or "potential" value, at about 30-year to 50-year recurrence interval. (The potential natural water loss is the maximum soil moisture deficiency in the root zone plus the 0.5 inch maximum interception loss.) Figure 4 indicates the average relationship between storm precipitation and recoverable water when both are expressed in terms of potential natural-water loss. By assuming arbitrary values of potential natural-water loss of 0.5, 1.5, 2.5, 3.5, 4.5, 5.5, and 6.5 inches, a family of curves with potential natural-water loss as a parameter is obtained. These curves are transformed to the curves shown in figure 5 where

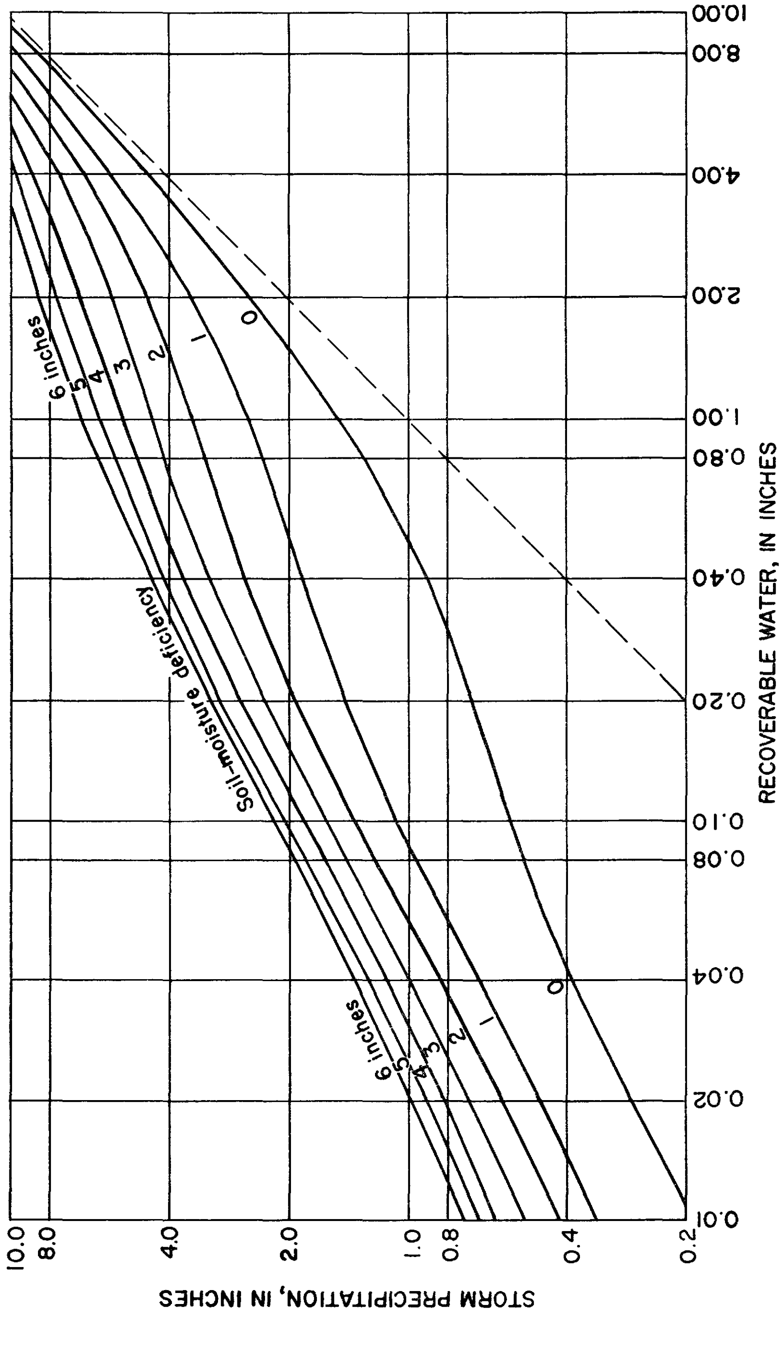

FIGURE 5.—Estimated relationship between storm precipitation, soil-moisture deficiency, and recoverable water on San Nicolas Island.

soil-moisture deficiency is used as a parameter. The transformation was accomplished by reducing the potential water loss parameter by 0.5 inches (the maximum interception loss). The curves of soil-moisture deficiency on figure 5 are the same as those of figure 3, plotted in more detail and to an expanded scale to permit a more accurate selection of values.

Although the relationships shown in figures 3, 4, and 5 are affected to some extent by variation in rates of infiltration and precipitation and by differences in types of soil, a study of observed precipitation and recoverable water in southern California indicates that the use of the relationships gives a more realistic picture of the recoverable water than would be obtained by using a constant ratio or single curve to express the relation between precipitation and runoff.

To estimate the amount of recoverable water from each storm event it is necessary to estimate the soil-moisture deficiency just prior to each storm. As the soil-moisture deficiency depends on antecedent conditions, these conditions must be incorporated into the estimate by a continuous inventory of the disposition of all precipitation from the beginning of the period under study. For example, assuming a maximum soil-moisture deficiency of 2 inches and assuming that this maximum deficiency existed October 1, 1933, a continuous inventory shows that the soil-moisture deficiency was at the maximum of 2 inches on October 1, 1953. The disposition of the precipitation on San Nicolas Island during the 1953–54 water year, assuming a maximum soil-moisture deficiency of 2 inches, is shown in table 7 as an example of part of the continuous inventory. Similar inventories were made for October 1, 1933 to September 30, 1955, assuming maximum soil-moisture deficiencies of 1, 2, and 4 inches at the beginning of the 22-year period.

The first step in developing table 7 was to divide the year into periods of days having precipitation and periods having no precipitation. The beginning and ending dates of each period are given in column 1 of the table. Next, the storm precipitation for each event was tabulated as shown in column 2. Then the appropriate interception loss was obtained from figure 5 and listed in column 3 for each storm. Column 4 of table 7 gives the depletion of the soil moisture in the root zone due to the evapotranspiration loss between periods of rainfall. This depletion is based on an island-wide estimated annual potential evapotranspiration loss of 19 inches distributed on basis of the following daily values:

Month	*Daily evapotranspiration*	*Month*	*Daily evapotranspiration*	*Month*	*Daily evapotranspiration*
October	0. 06	February	0. 03	June	0. 07
November	. 04	March	. 05	July	. 07
December	. 03	April	. 06	August	. 07
January	. 03	May	. 06	September	. 06

Table 7.—*Estimated disposition of 1953–54 precipitation, in inches, on San Nicolas Island*

Date		Precipitation	Interception loss	Evapotranspiration	Recoverable water	Soil moisture deficiency
October	1–31					2.00
November	1–13	0.10	0.10			2.00
	14	.81	.50		0.04	1.73
	15–30	.02	.02	0.27		2.00
December	1–31	.10	.10			2.00
January	1–10					2.00
	11–12	.79	.50		.04	1.75
	13–16			.12		1.87
	17–20	1.45	.50		.12	1.04
	21–22			.06		1.10
	23–25	.80	.50		.05	.85
	26–31			.18		1.03
February	1–12			.36		1.39
	13–15	.57	.46		.02	1.30
	16–28	.01	.01	.36		1.66
March	1–16			.34		2.00
	17	.36	.33		.01	1.98
	18–19			.02		2.00
	20–25	1.15	.50		.07	1.42
	26–29			.20		1.62
	30	.25	.23		.01	1.61
	31			.05		1.66
April	1–21			.26		1.92
	22–23	.14	.14			1.92
	24–26			.08		2.00
	27	.20	.20			2.00
	28–30					2.00
May	1–8					2.00
	9	.17	.17			2.00
	10–31					2.00
June	1–30					2.00
July	1–31					2.00
August	1–31					2.00
September	1–30					2.00

Annual precipitation .... inches .. 6.92
Estimated recoverable water .... do .... .36

The above values were based on the observed evaporation record at Chula Vista near San Diego.

These evapotranspiration losses exist only as long as the moisture in the root zone is available for plant use. The recoverable water for each storm period, as obtained from the curves of figure 5, is tabulated in column 5 of table 7. The last column of the table is the inventory of the soil-moisture deficiency. The deficiency at the end of each time period is obtained by reducing the soil-moisture deficiency at the beginning of the period by the difference between the storm precipitation and the sum of the interception loss and recoverable water.

The precipitation on the island for the water year 1953–54 amounted to 6.92 inches. Assuming a maximum soil-moisture deficiency of 2 inches at the beginning of the 22-year period and maintaining a continuous inventory, the recoverable water would be 0.36 inch in 1953–54. If the maximum soil-moisture deficiency were 4 inches instead of 2 inches, the recoverable water would be 0.19 inch; if it were 1 inch, then the recoverable water would be 0.70 inch.

The wide variation in the amount of recoverable water resulting from the use of different values of maximum soil-moisture deficiency indicates the importance of a proper appraisal of the island's soil mantle. On the basis of the geologic features of San Nicolas Island and a limited field inspection, the island was divided into four areas, A, B, C, and D which are outlined on the map of figure 6. Each area differs significantly from the other areas either with respect to soil-mantle characteristics, degree of vegetative cover, or amount of surface runoff.

Precipitation is considered to be more or less uniform over the entire island because of its small area and the fact that the maximum altitude is only about 900 feet. Therefore, the same storm precipitation data were used for all areas.

AREA A

The soil mantle of area A, the west end of the island, is chiefly recent dune sand. The vegetative cover is very sparse. Tule Creek, the only well defined stream channel in this area, is perennial along some of its length due to ground-water seepage. A large part of the water supply of the island is supplied by ground-water withdrawals from the upper Tule Creek area.

A maximum soil-moisture deficiency of 2 inches was assigned to area A for the purpose of estimating recoverable water. In making this selection, it was assumed that evaporation of soil moisture from the bare surface could occur to a depth of about 1 to 3 feet; also, that this evaporation, although less than transpiration, would not differ significantly from it.

The estimated monthly and annual (water year) figures of recoverable water, based on a maximum 2-inch soil-moisture deficiency, are presented in table 8. The estimated annual values range from 0.05 inch in the 1949 water year to 8.22 inches in the 1941 water year. The estimated average annual recoverable water of area A for the 22-year period is 1.50 inches, which is equivalent to about 17 percent of the 8.81 inches of mean annual precipitation.

It is estimated that about 90 percent of the recoverable water in area A will percolate directly to the main ground-water body and that only about 10 percent will occur as direct surface runoff. This estimate is based on the assumed permeability and high infiltration rates of the dune sands and is borne out by the lack of well-defined

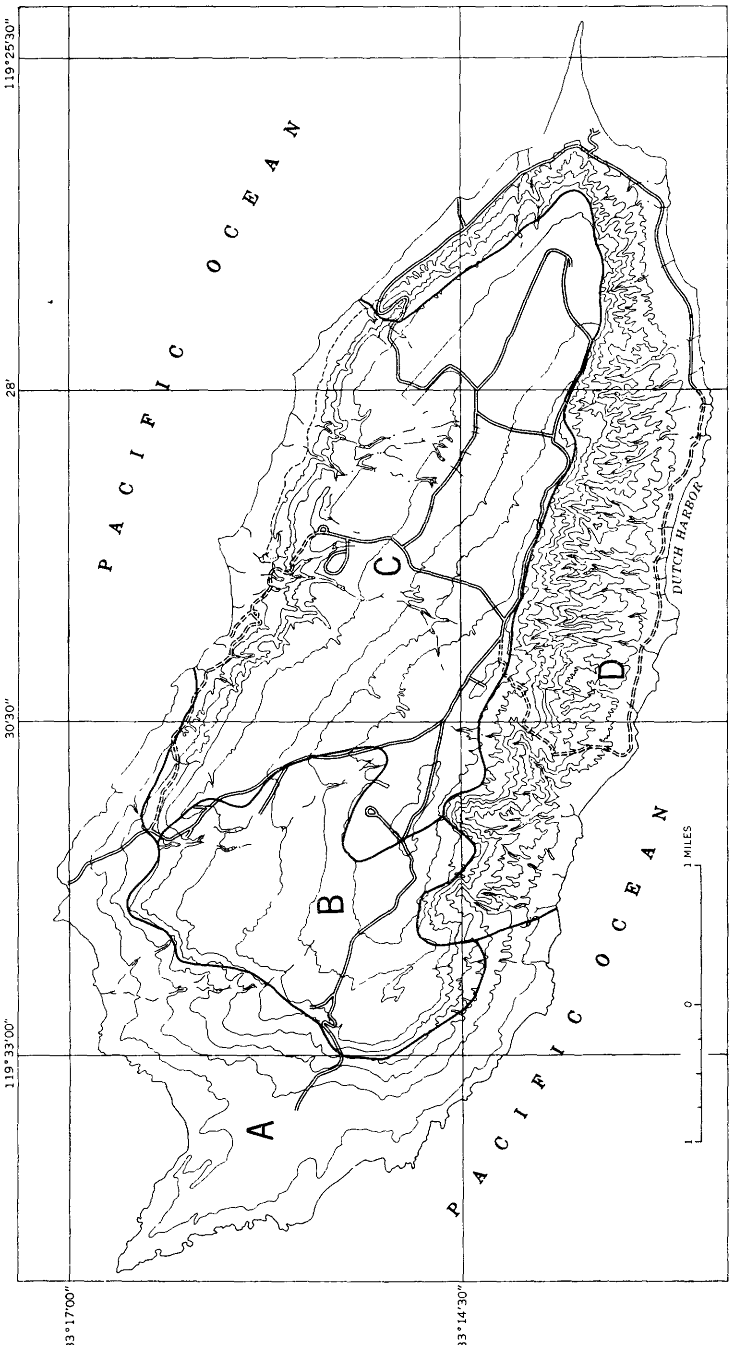

FIGURE 6.—Map of San Nicolas Island showing areas of different recoverable water characteristics.

TABLE 8.—*Estimated recoverable water, in inches, of area A or area B, San Nicolas Island, for water years 1934–55*

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1934	0	0	0.24	0	0.04	0	0	0	0	0	0	0	0.28
1935	0	.05	.06	.12	.04	.05	.10	0	0	0	0	0	.42
1936	0	0	.02	0	.38	0	0	0	0	0	0.07	0	.47
1937	0	0	.41	.08	1.75	1.07	0	0	0	0	0	0	3.31
1938	0	0	.21	0	.30	4.52	0	0	0	0	0	0	5.03
1939	.01	0	2.09	.13	.02	0	0	0	0	0	0	.12	2.37
1940	0	0	0	.33	.88	.06	.01	0	0	0	0	0	1.28
1941	.09	.02	2.00	2.25	1.36	2.46	.04	0	0	0	0	0	8.22
1942	.03	.01	.08	0	.06	.04	.12	0	0	0	0	0	.34
1943	.03	0	0	2.16	.19	.07	0	0	0	0	0	0	2.45
1944	0	.01	.18	.10	.55	.25	.05	0	0	0	0	0	1.14
1945	0	.09	.03	1.08	1.11	.12	0	0	0	0	0	0	2.43
1946	.03	0	1.55	0	.04	.01	.01	0	0	0	0	0	1.64
1947	0	.30	.16	0	0	0	0	0	0	0	0	0	.46
1948	0	0	.01	0	0	.05	0	0	0	0	0	0	.06
1949	0	0	.03	.01	0	.01	0	0	0	0	0	0	.05
1950	0	.02	.11	.02	.04	.01	.02	0	0	0	0	0	.22
1951	.01	.07	0	.02	.06	0	.04	0	0	0	0	0	.20
1952	0	0	.22	1.31	.06	.14	.02	0	0	0	0	0	1.75
1953	0	.08	.09	.13	0	.01	0	0	0	0	0	0	.31
1954	0	.04	0	.21	.02	.09	0	0	0	0	0	0	.36
1955	0	.02	.02	.03	.03	.01	.02	0	0	0	0	0	.13

stream channels and the fact that there is year-round ground-water seepage into the ocean at tide level along almost all of the coastline of area A. Also, there is seepage at higher altitudes in the few small canyons in the area.

AREA B

The soil cover of area B consists chiefly of older sands both cemented and uncemented. These sands are less permeable than the more recent sands of area A. The vegetative cover of area B, although denser than that of area A, would still be considered sparse. Tule Creek is the only well defined stream channel in the relatively flat terrain of the area.

A maximum soil-moisture deficiency of 2 inches was selected for area B on the basis of soil-mantle characteristics which are similar in some respects to those of area A. Because the precipitation and maximum soil-moisture deficiency are the same for both areas, the data on estimated recoverable water presented in table 8 apply to area B as well as area A. The only difference between the areas is the distribution of recoverable water between surface runoff and deep percolation. Because the older sand formation is more cemented and less permeable, it is assumed that in area B about 60 percent of the recoverable water would take the form of direct surface runoff and about 40 percent would percolate directly to the ground water. This of course is only a general approximation covering all of area B. There may be parts of the area where almost all of the recoverable water percolates directly to the ground water and other parts where almost all recoverable water would occur as surface runoff.

AREA C

Area C is the largest of the areas and consists chiefly of marine terrace cover overlying the north-central part of the island. The average soil-mantle thickness is about 1 to 2 feet. Much of the area is covered by vegetation which ranges from a fairly heavy growth of scrub and chaparral in the northwestern part of the area to dwarfed scrub and annual grasses and weeds in the remainder of the area. There are several ephemeral stream systems rather deeply intrenched in the area indicating that there is considerable surface runoff at times.

On the basis of available information, a maximum soil-moisture deficiency of 4 inches was selected for area C. From this estimate and the data on storm precipitation, the monthly and annual figures of recoverable water were estimated as given in table 9. The estimated annual values range from 0.01 to 6.15 inches. The average annual recoverable water for the water years 1934-55 is 0.76 inch which is about 9 percent of the mean annual precipitation for the same period.

The soil mantle of area C is relatively impermeable, consisting of fairly fine claylike particles which tend to swell when wet. There are numerous small dry washes and gullies traversing the area indicating considerable surface flow at times; but there are very few, if any, ground-water seeps in the area—a sign of limited ground-water storage. On the basis of these observations it is estimated that about 90 percent of the recoverable water of area C will take the form of surface runoff and only about 10 percent will percolate below the root zones to become groundwater.

TABLE 9.—*Estimated recoverable water, in inches, of area C, San Nicolas Island, for water years 1934–55*

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1934	0	0	0.13	0	0.02	0	0	0	0	0	0	0	0.15
1935	0	.03	.03	.07	.02	.03	.06	0	0	0	0	0	.24
1936	0	0	.01	0	.19	0	0	0	0	0	.04	0	.24
1937	0	0	.20	.03	.45	.70	0	0	0	0	0	0	1.38
1938	0	0	.11	0	.15	2.78	0	0	0	0	0	0	3.04
1939	0	0	.70	.07	.01	0	0	0	0	0	0	.07	.85
1940	0	0	0	.16	.22	.04	.01	0	0	0	0	0	.43
1941	.05	.01	.54	1.68	1.36	2.46	.05	0	0	0	0	0	6.15
1942	.01	0	.04	0	.04	.02	.06	0	0	0	0	0	.17
1943	.02	0	0	.57	.11	.05	0	0	0	0	0	0	.75
1944	0	0	.10	.06	.22	.09	.03	0	0	0	0	0	.50
1945	0	.05	.01	.39	.31	.07	0	0	0	0	0	0	.83
1946	.02	0	.52	0	.03	.01	0	0	0	0	0	0	.58
1947	0	.15	.08	0	0	0	0	0	0	0	0	0	.23
1948	0	0	0	0	0	.02	0	0	0	0	0	0	.02
1949	0	0	.01	0	0	0	0	0	0	0	0	0	.01
1950	0	.01	.06	0	.02	0	.01	0	0	0	0	0	.10
1951	0	.04	0	.01	.03	0	.01	0	0	0	0	0	.09
1952	0	0	.13	.35	.04	.08	.01	0	0	0	0	0	.61
1953	0	.04	.04	.04	0	0	0	0	0	0	0	0	.12
1954	0	.02	0	.12	.01	.04	0	0	0	0	0	0	.19
1955	0	.01	0	.01	.01	0	.01	0	0	0	0	0	.04

AREA D

The steep narrow band along the south and west sides of the island has been designated as area D. Here the stream systems are numerous and well defined; canyons and gullies cut deep into the bedrock. Generally, the drainage areas are less than 1 mile long with a maximum altitude ranging from 500 to 800 feet. Over most of the area the bedrock of Eocene sandstones, siltstones, and shales is exposed. There is practically no soil mantle and very little vegetative growth. On the basis of these conditions a maximum soil-moisture deficiency of 1 inch was assigned to area D.

The estimated monthly and annual figures of recoverable water for area D, based on the assumed 1-inch soil-moisture deficiency, are given in table 10. The estimated annual values range from 0.07 to 9.30 inches. The average annual value for the 22-year period 1933-55 is 2.13 inches which is equivalent to about 24 percent of the mean annual precipitation.

It is estimated that nearly all of the recoverable water on area D takes the form of surface runoff and discharges rapidly into the ocean. Because of the steep slopes, short drainages, lack of suitable reservoir sites, and rapidity of discharge to the ocean, it is doubtful that very much of the recoverable water in area D could be salvaged for use on the island.

TABLE 10.—*Estimated recoverable water, in inches, of area D, San Nicolas Island, for water years 1934–55*

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1934	0.01	0	0.52	0	0.06	0	0	0	0	0	0	0	0.59
1935	.01	.10	.10	.24	.06	.08	.18	0	0	0	0	0	.77
1936	0	0	.04	.01	.98	0	0	0	0	0	.11	0	1.14
1937	0	0	.97	.14	2.13	1.13	0	0	0	0	0	0	4.37
1938	0	0	.42	0	.84	5.03	0	0	0	0	0	.01	6.30
1939	.01	0	3.09	.14	.02	0	0	0	0	0	0	.22	3.48
1940	0	0	0	.85	1.46	.10	.04	0	0	0	0	0	2.45
1941	.14	.02	2.98	2.26	1.39	2.46	.05	0	0	0	0	0	9.30
1942	.05	.01	.13	0	.11	.07	.18	0	0	0	0	0	.55
1943	.05	0	0	3.16	.20	.07	0	0	0	0	0	0	3.48
1944	0	.02	.38	.19	1.35	.28	.08	0	0	0	0	0	2.30
1945	0	.14	.04	2.08	1.11	.12	0	0	0	0	0	0	3.49
1946	.05	0	2.55	0	.05	.03	.02	0	0	0	0	0	2.70
1947	0	.72	.27	0	0	0	0	0	0	0	0	0	.99
1948	0	0	.02	0	0	.07	0	0	0	0	0	0	.09
1949	0	0	.04	.02	0	.01	0	0	0	0	0	0	.07
1950	0	.03	.22	.03	.07	.01	.03	0	0	0	0	0	.39
1951	.01	.12	0	.05	.09	.01	.05	0	0	0	0	0	.33
1952	0	0	.49	2.06	.06	.16	.01	0	0	0	0	0	2.78
1953	0	.11	.13	.13	0	.01	.01	0	0	0	0	0	.39
1954	0	.06	0	.47	.04	.13	0	0	0	0	0	0	.70
1955	0	.05	.03	.05	.04	.01	.03	.01	0	0	0	0	.22

SUMMARY OF RECOVERABLE WATER

Although tables 8, 9, and 10 show the estimated recoverable water to two or three significant figures, the actual recoverable water for individual months may be grossly in error. Considerable personal judgment was involved in the selection of the soil-moisture capacity values and the shape of the curves of figures 3, 4, and 5. However, these tables are believed to present a reliable indication of the probable distribution of recoverable water during the 22-year period 1933–55; and the average values derived from the data are considered to be of about the right magnitude and representative of a long-time period.

Cumulative mass diagrams of estimated recoverable water for areas A, B, C, and D are shown on figure 7. These diagrams indicate

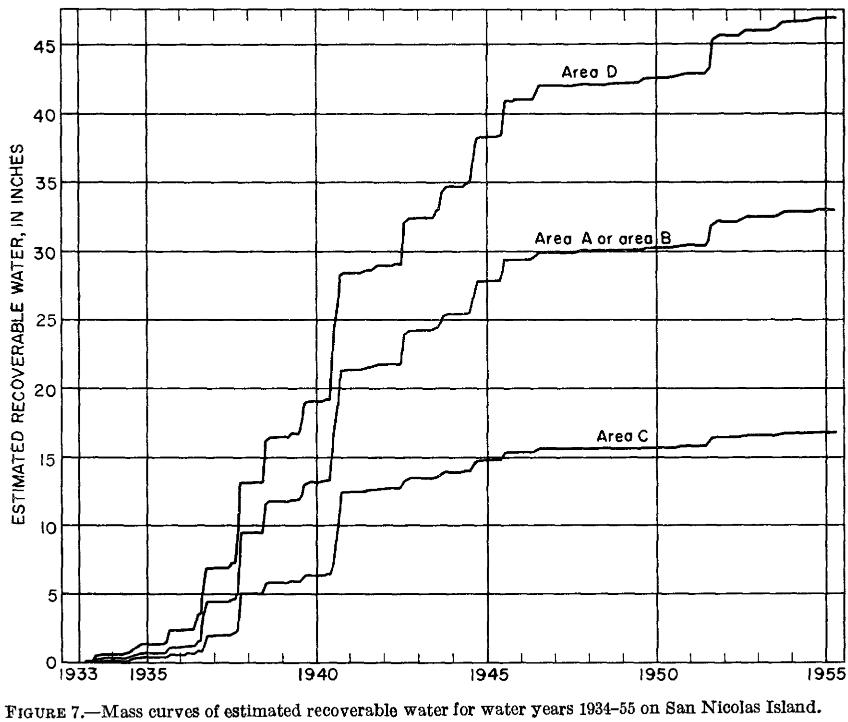

FIGURE 7.—Mass curves of estimated recoverable water for water years 1934–55 on San Nicolas Island.

graphically the magnitude and distribution of the potential water supply during the years 1934–55.

To lend further emphasis to the extreme variation of recoverable water from month to month and year to year on San Nicolas Island, table 11 was prepared to indicate maximum and minimum recoverable water occurring during selected consecutive time periods. The data show, for example, that 10 to 16 percent of the total estimated recoverable water occurred in 1 month. Also, that the estimated recoverable water for the 6 wettest years was from 10 to 20 times greater than that for the 6 driest years.

TABLE 11.—*Periods of maximum and minimum estimated recoverable water, in inches, on San Nicolas Island*

Consecutive time periods [1]	Maximum recoverable water			Minimum recoverable water		
	Area A or B	Area C	Area D	Area A or B	Area C	Area D
Months:						
1	4.52	2.78	5.03	0	0	0
3	6.07	5.50	6.63	0	0	0
6	8.18	6.10	9.25	0	0	0
12	8.22	6.15	9.30	.01	0	.02
Years:						
2	9.62	6.63	11.94	.09	.03	.13
4	16.94	10.48	21.59	.41	.17	.68
6	20.78	12.13	27.19	1.27	.53	2.46

[1] 22-year period 1933-55:

	Area A or B	Area C	Area D
Total .... inches	32.97	16.72	46.88
Average annual .... do	1.50	.76	2.13
Average monthly .... do	.12	.06	.18

Although the estimated monthly and annual totals of recoverable water may appear small, they are comparable to observed values for similar areas on the mainland. For example, the average annual recoverable water of the Murrieta Creek drainage, a coastal foothill area in the Santa Margarita River basin, is 0.8 inch—or about 5 percent of the 14.9 inches average annual precipitation. Average annual recoverable water of San Nicolas Island, as estimated in this report, ranges from 9 to 24 percent of the average annual precipitation.

It should be pointed out that as small as the estimated values of recoverable water are, the amount that could be developed is considerably smaller. The extreme variability of runoff indicates that a large amount of storage would be required to smooth out these variations. Even if sufficient surface and ground-water storage sites were available, the attendant losses by evaporation and seepage would decrease the amount of water available for use.

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