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TECHNICAL COMPLETION REPORT

April 1980

WATER QUALITY OF A RESERVOIR USED FOR RECLAIMED WATER STORAGE

TECHNICAL COMPLETION REPORT

ORWT PROJECT # A-070-CAL
(W - 551)

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ABSTRACT

The water quality of two reservoirs receiving differing amounts of reclaimed water is compared with a neighbouring reservoir receiving none. Monthly sampling of chemical parameters is presented, together with analyses of dissolved and suspended solids (the latter fractionated into sized components). Quantitative estimation of algal populations presented little significant information although measurement of algal growth potential, using the *Selenastrum capricornutum* "bottle test", gave data of considerable importance for reservoir management.

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CHAPTER I

PREFACE

The research leading to this report was supported by the University of California Water Resources Center, as part of Water Resources Center Project UCAL-WRC 551 entitled "Water Quality of a Reservoir used for Reclaimed Water Storage".

We wish to thank the Water Resources Center for support of this project; Ms. M. Talebi, Mr. A. Accuedo, V. Diyamandoglu, Ms. M. Friedrich and Ms. J. Gunter (student assistants) for their work on this project; Mrs. Carol Justice for acting as Laboratory Manager during the investigations and Mr. C. Kuo and Ms. D. Franks for their technical support.

We are indebted to the Irvine Ranch Water District for permission to work at Rattlesnake and Sand Canyon Reservoirs and to The Irvine Company for permitting access to their property in order to reach the reservoirs.

CHAPTER II

INTRODUCTION

Water availability is becoming increasingly critical in southern California, Potential shortages are becoming apparent, both of potable water and of water usable for industrial or agricultural purposes. As a consequence, attempts are being made to increase usage of reclaimed water because discharge of sewage effluent to the ocean represents a loss of water which is potentially usable. The use of reclaimed water as a source of potable water is precluded by various health-related problems, although its use in industry or agriculture is much more likely as the restrictions on its use are much less stringent. One of the major difficulties with using reclaimed water for industrial or agricultural purposes is that demand is highly seasonal in agriculture and slightly so for industry, while production is continuous. As a consequence, reclaimed water needs to be stored during those times when demand is less than production, for use at a later time. The production of excess reclaimed water in southern California occurs during the period of winter rains, so that there are two sources of excess water, with little demand for its use.

Locally, for the past decade, impoundments build originally for flood control purposes and for the storage of run-off to be used in the dry season for irrigation are being used also for the storage of excess reclaimed water. Unfortunately, the basic planning on which this storage of reclaimed water was initiated made the basic assumption that water of any origin could be stored indefinitely until needed, without change in its chemical and biological characteristics. As a consequence there have been various technical problems, such as the blocking of valves, screens and sprinkler heads.

Little is known of the limnology of small impoundments and nothing appears to have been published on the seasonal characteristics of small impoundments receiving reclaimed water. The present investigation was intended to produce data on the chemical, physical, and biological characteristics of small impoundments receiving reclaimed water. In the course of the initial studies, it became apparent that the two reservoirs selected for this study (Rattlesnake Reservoir, Sand Canyon Reservoir) would not provide a sufficient data base without some means of comparison. Santiago Reservoir is a reservoir adjacent to the two reservoirs under consideration, but differing from them in that it receives no reclaimed water. In the second year of study, comparable investigations were made not only on the two reservoirs receiving reclaimed water but also on Santiago Reservoir.

In order to ascertain if there were differences between the input streams from the watersheds to the three reservoirs, attempts were made to obtain samples from these input streams. This is not easy in that the input streams flow for only a short time after a winter rainstorm and in the absence of tracks in the watersheds, movement is virtually impossible after rain. However, certain samples were collected and analysed for algal growth-promoting nutrients. Analyses of the reclaimed water from the Michelson Reclamation Plant of the Irvine Ranch Water District for concentrations of algal growth-promoting nutrients were obtained from the Irvine Ranch Water District.
As there is local concern over the impact of water release from Rattlesnake and Sand Canyon Reservoirs, either deliberately or accidentally, samples of released water were also obtained for analysis.

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CHAPTER III

THE HISTORY AND CHARACTERISTICS OF SANTIAGO, RATTLESNAKE AND SAND CANYON RESERVOIRS

Introduction

The highly seasonal rains which occur in southern California were a serious menace to the development of agriculture in Orange County at the end of the last century and the beginning of the present century. There was an excess of water during the winter rains (December through February) or a shortage during the remainder of the year. To control flood damage, drainage channels were constructed in various parts of the watershed and impoundments were constructed in many valleys of the area. The primary function of these impoundments was to control excess run-off during the rainy season and to make the water available during the following dry season. As conditions changed in the watershed so that agriculture declined slightly in importance and urban development occurred, the functions of many impoundments began to change. Recreational activities at bodies of water close to urban developments increased in importance while the need to store reclaimed water during the 'wet' season became imperative.

The histories of the three reservoirs used in the present study are as follows:

Santiago Reservoir

The authorization for construction of the dam which created Santiago Reservoir was embodied in an agreement dated 6 February 1928 between The Irvine Company and two irrigation districts, the Carpenter Irrigation District and the Serrano Irrigation District (Lowry & Associates, 1973). The two irrigation districts were empowered to contruct the dam and the Irvine Company participated by payment of 50% of the construction costs. The dam was constructed in 1931 and is of the rolled earth-fill embankment type, with a height of 130 ft. The reservoir initially had a storage capacity of 18,600 acre-feet of water. The maximum water depth in the reservoir was initially of the order of 110 ft although it would appear to have been reduced by sedimentation during the past 50 years as a depth in excess of 90 ft could never be detected during the present study.

The subsequent history of this reservoir is complicated. In terms of ownership, The Irvine Company acquired the 50% interest of Carpenter Irrigation District in 1970, while in 1971 The Irvine Company transferred its 50% interest in Santiago Dam and the lands underlying Santiago Reservoir to the Irvine Ranch Water District. In terms of water passing to Santiago Reservoir, the initial input was derived entirely from surface run-off in upper Santiago Creek. In 1956, the Metropolitan Water District of Southern California constructed the Santiago Lateral for the purpose of providing replenishment water to Santiago Reservoir and, ultimately, of providing irrigation water to Orange County. The output from Santiago Reservoir was used initially by the Irvine Company who constructed an aqueduct in the late 1930's, the so-called Highline Canal, which connected Santiago Reservoir with various smaller reservoirs on their property. The water provided initially was derived entirely from surface run-off in upper Santiago Creek although after construction of the Santiago Lateral in 1956, the water provided was a blend of run-off and Colorado River water supplied by the Metropolitan Water District of Southern California. Another aqueduct, the Santiago Aqueduct, was constructed in 1962 following formation of the Santiago Aqueduct Commission in 1961. The function of this structure was to supply water from Santiago Reservoir (by this time a blend of surface run-off and Colorado River water) to various water districts in eastern Orange County, rather than directly to the Irvine Ranch. Finally, Santiago Reservoir acquired a recreational function with the development of 'Irvine Lake' by which name Santiago Reservoir is now better known locally.

In terms of water content, Santiago Reservoir still receives a blend of local run-off from upper Santiago Creek and Colorado River water from the Municipal Water District of Southern California, but no reclaimed water.

Rattlesnake Reservoir

Rattlesnake Reservoir was created through the construction of the Rattlesnake Canyon Dam in 1941, by The Irvine Company. The dam consists of an earth embankment, some 62 ft high. As originally constructed, the reservoir had a maximum capacity of 1,440 acre-feet, with a maximum depth of 46 ft. Subsequently, sedimentation has reduced the depth by about 4 ft while a deep layer of accumulated organic debris has developed in the lowermost levels of the reservoir. The original purpose of this reservoir was to impound surface surface run-off in Rattlesnake Canyon for irrigation purposes. Following construction of the Highline Canal, water to be used for irrigation began to be transferred from Santiago Reservoir. As explained previously, this water was initially derived from run-off although since 1965, it consists of a blend of run-off and Colorado River water. Finally, in 1975, the reservoir was transferred from the Irvine Company to the Irvine Ranch Water District and reclaimed water began to be stored in it in the following year. Thus, at the present time, the water in the reservoir is derived from three sources: natural run-off, Colorado River water, and reclaimed water. The reservoir has been used for shooting and fishing purposed by a private club for several years, alhough there is no general public access.

Sand Canyon Reservoir

Sand Canyon Reservoir was created through the construction of Sand Canyon Dam in 1941 by The Irvine Company. The dam consists of an earth embankment, some 55 ft high. As originally constructed, the reservoir had a maximum capacity of 654 acre-feet with a maximum depth of 46 ft, although later modifications have since increased both capacity and maximum depth. Sedimentation since construction has reduced the maximum depth somewhat as a depth greater than 40 ft was never detected during the present study. The original primary function of Sand Canyon Reservoir was to impound surface run-off in Sand Canyon for irrigation purposes although the reservoir seems never to have lived up to its promise, probably because it was constructed in the lee of the San Joaquin hills and was therefore in a 'rain shadow'. In 1967, the dam and reservoir were transferred from The Irvine Company to the Irvine Ranch Water District for the storage of reclaimed water for irrigation purposes. A short time thereafter, the Sand Canyon Land outfall was constructed to convey reclaimed water from the Michelson Water Reclamation Plant which reclaims domestic sewage generated in the service area of the Irvine Ranch Water District (Lowry & Associates, 1977). At the present time, Sand Canyon Reservoir receives surface run-off and is supplied with reclaimed water. It has no recreational function.

CHAPTER IV

LIMNOLOGICAL CHARACTERISTICS OF SANTIAGO, RATTLESNAKE AND SAND CANYON RESERVOIRS

Introduction

As was shown in Chapter II, all three reservoirs are relatively shallow. Sand Canyon and Rattlesnake Reservoirs are of small surface area although Santiago Reservoir is much larger. Shallow bodies of water in southern California occurring at low altitudes tend to behave as monomictic systems, with one period of general mixing occuring during the year, in the winter months.

Temperature and dissolved oxygen in Santiago, Rattlesnake and Sand Canyon Reservoirs

Measurements of temperature and dissolved oxygen were obtained with an IBC Temperature/Dissolved Oxygen meter, using a 50 ft cable and a probe with agitation.

Measurements of temperatures were made on several occasions to give profiles with depth in all three reservoirs. The results are shown in Figure 1 (Santiago Reservoir), Figure 2 (Rattlesnake Reservoir, and Figure 3 (Sand Canyon Reservoir), for both typical winter and summer conditions. The water temperatures are obviously higher during the summer months than during the winter. Because of their extreme shallowness, a marked temperature stratification was not present in either Rattlesnake (Figure 2) or Sand Canyon (Figure 3) Reservoirs during the summer months although such a stratification did occur in Santiago Reservoir (Figure 1) because of its greater depth.

Measurements of dissolved oxygen were also made at the same time as temperature because the comparison between the two profiles provides a considerable amount of useful information about conditions in a body of

FIGURE 1

SANTIAGO RESERVOIR: WINTER AND SUMMER PROFILES OF TEMPERATURE AND DISSOLVED OXYGEN

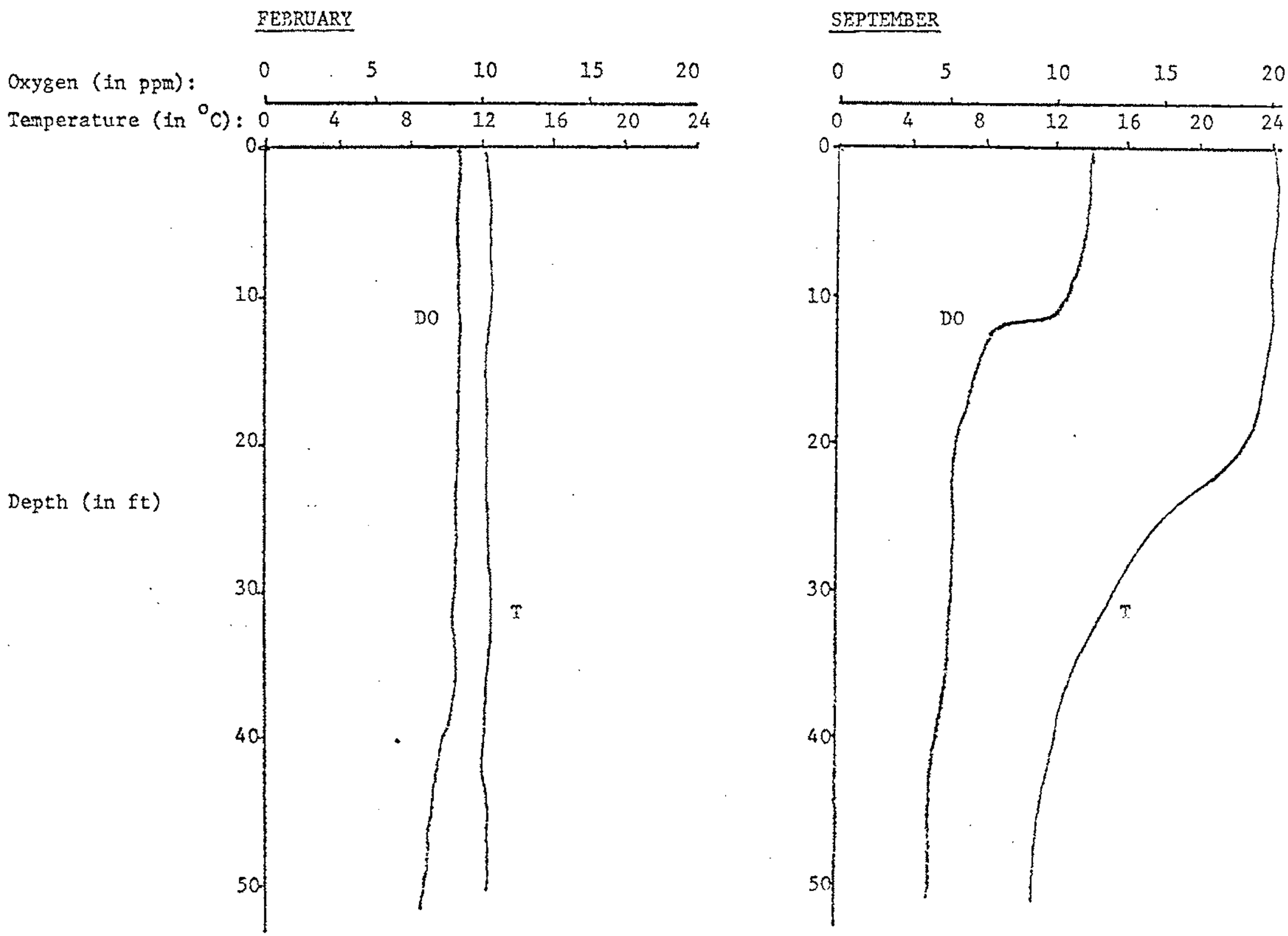


FIGURE 2

RATTLESNAKE RESERVOIR: WINTER AND SUMMER PROFILES OF TEMPERATURE AND DISSOLVED OXYGEN

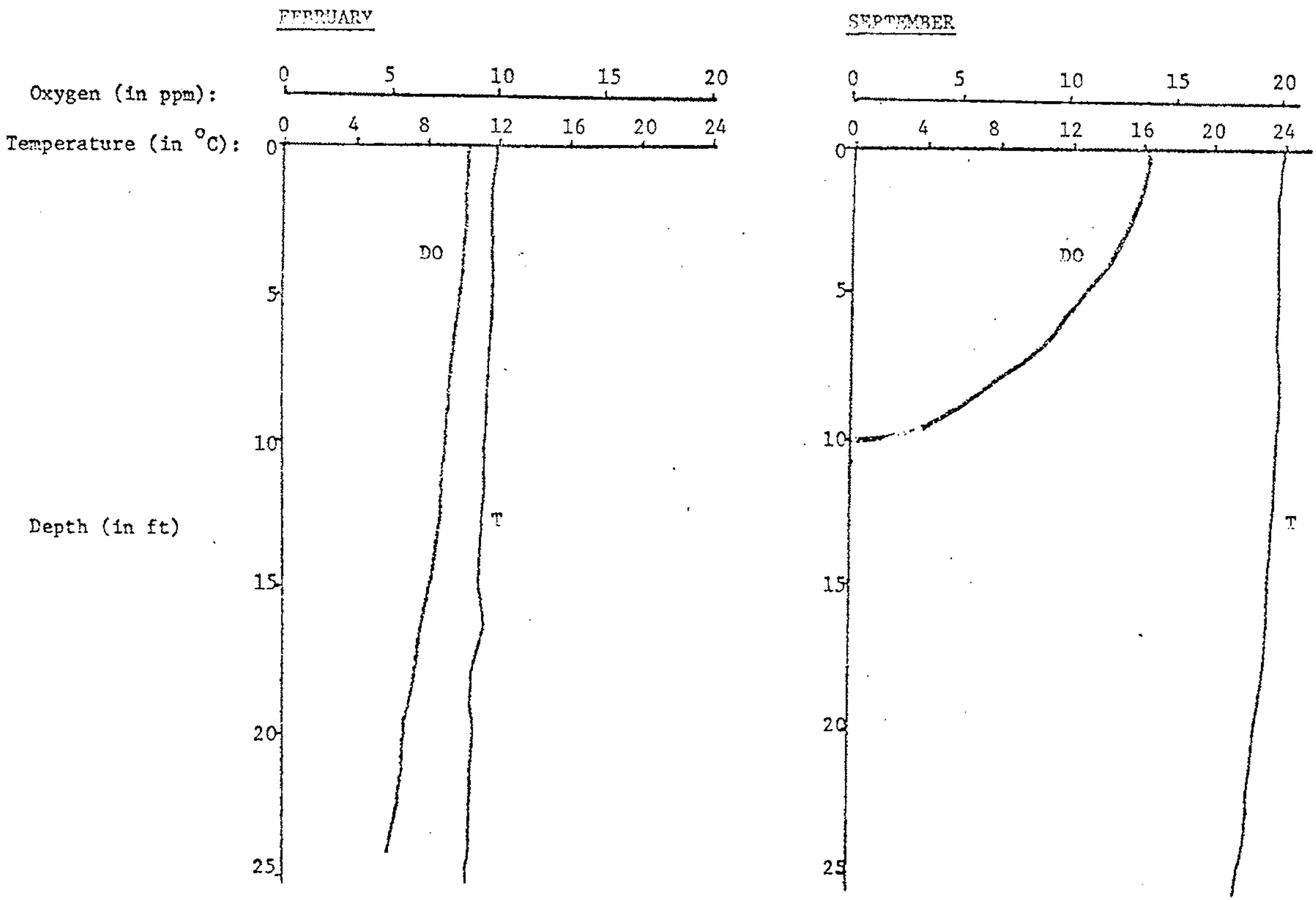
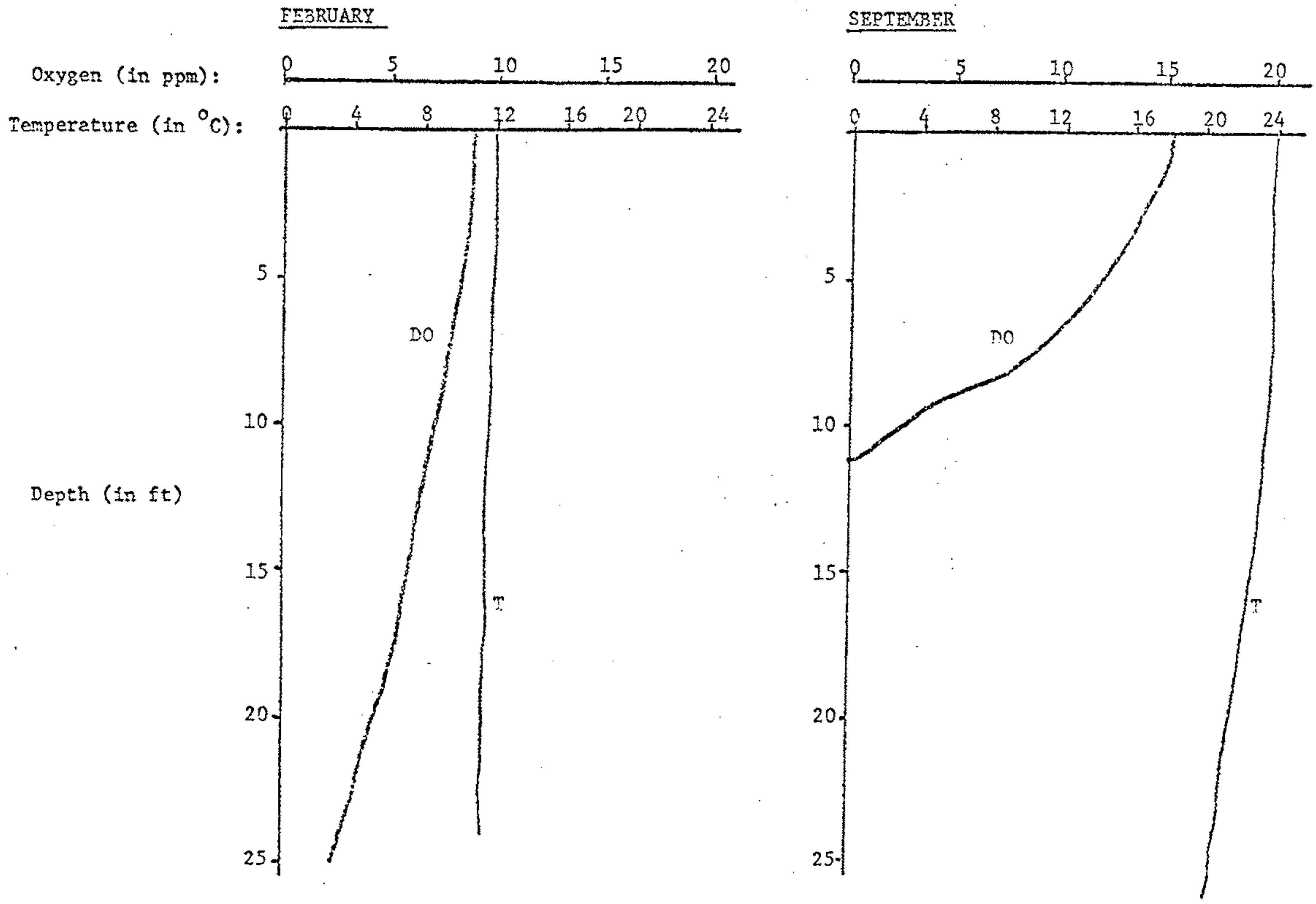


FIGURE 3

SAND CANYON RESERVOIR: WINTER AND SUMMER PROFILES OF TEMPERATURE AND DISSOLVED OXYGEN



water. The amount of oxygen present at any time and at any position on the depth profile depends, firstly on the temperature dependence of oxygen solubility and, secondly, on the biological modification of the amount present. Oxygen may be produced by photosynthesis in the uppermost layers while respiration will deplete oxygen levels. The latter is particularly important in the lowermost levels of a lake in which organic materials have accumulated and bacterial metabolism is active.

Santiago Reservoir has little growth of algae so that photosynthetic production of oxygen in the uppermost layers is limited. The limited growth of algae in this reservoir results in the least deposition of organic material in bottom deposits so that oxygen depletion in the lowermost layers of the lake is never complete. As a consequence of these effects of algal growth, the oxygen concentration at the surface was only slightly supersaturated during September, while at depth the oxygen concentration never fell to zero.

Conditions in Rattlesnake and Sand Canyon Reservoirs, both of which receive reclaimed water are very different. The levels of algal growth are much greater so that in September the degree of supersaturation in surface water is greater. The accumulated organic bottom deposits are much greater so that even in February, with considerable mixing taking place, oxygen levels below a depth of 20 ft are considerably reduced. In September, when mixing is minimal, oxygen levels below a depth of 10 ft in Rattlesnake Reservoir and 12 ft in Sand Canyon Reservoir had fallen to zero.

From the above observations, it will be apparent that in a shallow reservoir (such as those under investigation) the oxygen profile gives a much better indication of the occurrence of mixing than temperature. In both Rattlesnake and Sand Canyon Reservoirs there was very little difference in temperature between surface and bottom waters in September. Superficially, this lack of temperature stratification might suggest that mixing was likely to occur. Consideration of the oxygen profile shows, however, that no mixing was taking place.

In previous years, a partial breakdown of stratification in Rattlesnake Reservoir has occurred in some years although there appear to be no reports of its occurrence in Sand Canyon or Santiago Reservoirs. These partial breakdowns have all occurred in the fall, coincident with lowered water levels and inclement weather conditions, and have important biological consequences particularly in terms of noxious odors and fish kills. Deoxygenation and organic bottom deposits give high concentrations of ammonia in the lowermost water and the consequences listed above are probably due to this coming to the surface with the partial destratification. It is probable that the reports of the occurrence of partial destratification in Rattlesnake Reservoir, but apparently not in Sand Canyon Reservoir, may well be due to the fact that there is a fishing and hunting club operating on the former. There are thus more people in the vicinity of Rattlesnake Reservoir, people interested in fish and fishing. Unfortunately, no such partial breakdown of stratification occurred during the period of the present investigation because it would have given valuable information on what happens to chemical and biological parameters during partial destratification.

CHAPTER V

WATER QUALITY STUDIES OF SANTIAGO, RATTLESNAKE AND SAND CANYON RESERVOIRS: CHEMICAL ANALYSES

Introduction

The basic studies of the three reservoirs conducted during the present investigation consisted of:

1. Chemical analyses, particularly of those materials which promote algal growth or which might be inhibitory to it
2. Biological analyses of the algal populations present in the three reservoirs
3. Analyses of the variation in dissolved and suspended solids in the three reservoirs.
4. Investigations of the algal growth potential of the waters of the three reservoirs.

As will be seen, these four types of investigation are all inter-related. The chemical components will be considered in the present Chapter, with the three remaining topics considered in subsequent Chapters.

Methods

Water samples from the three reservoirs were collected on an approximately monthly schedule during the two years of the study. In addition, certain results obtained prior to the commencement of the present grant are also included to increase coverage. The basic sampling was conducted using the UCI Water Resources Laboratory integrating sampler, which collects an overall sample from throughout the water column. Approximately two gallons were collected on each occasion and then divided between the various operations being undertaken. Grab sampling was also used on occasions in collections from the imput and output streams.

Chemical analytical techniques

Analytical determinations were performed in accordance with accepted standard methods, although these changed during the course of the present investigation following acquisition of autoanalytic equipment.

Prior to the introduction of autoanalytic procedures, the methods used were as follows:

(1) Nitrate/nitrite: "Standard Methods" (American Public Health Association, 1975), section 419C, Cadmium reduction method.

(2) Ammonia: "Standard Methods" (American Public Health Association, 1975), section 418C, Phenate method.

(3) Phosphate: "Standard Methods" (American Public Health Association, 1975), section 425F, Ascorbic acid method.

(4) Total phosphorus: "Standard Methods" (American Public Health Association, 1975), section 425C, III, Persulfate digestion method.

(5) Total Kjeldahl Nitrogen: "Standard Methods" (American Public Health Association, 1975), section 421.

Following the introduction of automated analysis in the Water Resources Laboratory at UC Irvine, the following methods were used:

(1) Nitrate/nitrite: "Standard Methods" (American Public Health Association, 1975), section 605, Cadmium reduction method.

(2) Phosphate: "Standard Methods" (American Public Health Association, 1975), section 606, Ascorbic Acid reduction method.

(3) Ammonia: Technicon (1972-7), Industrial method no. 329-74 w/B; automated salicylate and nitroprusside method.

(4) Total Phosphorus: Technicon (1972-7), Industrial method no. 376-75 w/A; potassium sulfate/sulfuric acid mixture digestion method, using block digestor, followed by Industrial method no. 329-74 w/B.

(5) Total Kjeldahl Nitrogen: Technicon (1972-7), Industrial method no. 376-75 w/A; potassium sulfate/sulfuric acid mixture digestion method, using block digestor, followed by Industrial method no. 329-74 w/B.

Most of the samples collected during the present investigation were analyzed using the autoanalytic procedures.

The analyses for heavy metals were conducted using the following procedures:

(1) Pb, Cr, Cu, and Cd: Perkin-Elmer (1977), using flameless atomic absorption spectrophotometry (flameless atomization).

(2) Fe, and Zn: U.S. Environmental Protection Agency (1974), using flame atomic absorption spectrophotometry (direct aspiration).

(3) Hg: U.S. Environmental Protection Agency (1974), using flameless atomic absorption spectrophotometry (cold vapor technique).

Internal quality control programs included routine analyses of control samples supplied by the Environmental Protection Agency and Environmental Research Associates Inc. In addition, designated samples were analyzed repeatedly to obtain data for the construction of control charts and to give information regarding long-term sample storage. Finally, "spiked" samples were used to determine percent recovery. Four to six standards were analyzed with each group of samples with a curve-fitting program used to determine slope, intercept and coefficient of correlation for the standard curve. These data were used in the calculation of sample concentrations. Analyses were repeated if the coefficient of correlation was less than 0.98 or if the control samples were outside the limits determined by the control charts.

Quality assurance included participation in the program conducted by the State of California Department of Health for State Certified Laboratories. The UCI Water Resources Laboratory has been certified for complete bacteriological and chemical analyses since May 1973.

Results

The results obtained for chemical analyses of algal growth-promoting nutrients are shown for Santiago Reservoir (Table 1), Rattlesnake Reservoir (Table 2) and Sand Canyon Reservoir (Table 3). A consolidated summary for the three reservoirs is shown in Table 4. The results for heavy metals are shown for Santiago Reservoir (Table 5), Rattlesnake Reservoir (Table 6) and Sand Canyon Reservoir (Table 7). The results of chemical analyses of the input streams to the three reservoirs are shown for algal growth-promoting nutrients (Table 8) and heavy metals (Table 9). The data supplied for the effluent from the Michelson Reclamation Plant are shown in Table 10. The chemical analyses of the released water from Rattlesnake and Sand Canyon Reservoirs are shown for plant growth-promoting nutrients (Table 11) and heavy metals (Table 12).

Discussion

The results of these chemical investigations show enormous variation between the reservoirs and in each reservoir from month to month. However, certain general conclusions can be drawn from the results obtained. In

TABLE 1

SANTIAGO RESERVOIR: CONCENTRATIONS OF PLANT GROWTH-PROMOTING NUTRIENTS

Date of Sample	Ortho-phosphate (as mg/l P)	Total Phosphate (as mg/l P)	Nitrate-nitrite (as mg/l N)	Ammonia (as mg/l N)	Total Kjeldahl Nitrogen (as mg/l N)
20 Jan 78	< 0.05	0.09	0.42	0.06	0.11
22 Feb 78	0.15	0.19	0.60	0.05	0.89
16 Mar 78	0.13	0.17	1.21	0.14	1.20
19 Apr 78	0.44	0.45	1.18	0.17	2.63
24 May 78	0.11	0.50	0.28	0.05	0.55
14 Jun 78	0.11	0.80	0.08	0.10	0.69
19 Jul 78	0.07	0.80	0.05	< 0.05	0.59
15 Aug 78	< 0.05	0.05	0.05	< 0.05	0.50
25 Sep 78	< 0.05	0.07	< 0.05	< 0.05	0.56
19 Oct 78	0.12	0.45	< 0.05	< 0.05	0.52
29 Nov 78	0.06	< 0.05	< 0.05	0.06	0.19
15 Dec 78	0.05	< 0.05	< 0.05	0.07	0.24
19 Jan 79	0.76	1.23	< 0.05	0.06	1.48
15 Feb 79	< 0.05	< 0.05	0.20	0.07	0.35
15 Mar 79	0.05	< 0.05	0.12	0.07	0.63

TABLE 1 (continued)

SANTIAGO RESERVOIR: CONCENTRATIONS OF PLANT GROWTH-PROMOTING NUTRIENTS

Date of sample	Ortho-phosphate (as mg/l P)	Total Phosphate (as mg/l P)	Nitrate-nitrite (as mg/l N)	Ammonia (as mg/l N)	Total Kjeldahl Nitrogen (as mg/l N)
14 Apr 79	< 0.05	< 0.05	0.18	0.06	0.54
17 May 79	< 0.05	0.06	0.08	< 0.05	0.50
19 Jun 79	< 0.05	< 0.05	< 0.05	< 0.05	0.48
26 Jul 79	< 0.05	< 0.05	< 0.05	0.06	0.43
15 Aug 79	< 0.05	< 0.05	< 0.05	< 0.05	0.43
10 Sep 79	< 0.05	< 0.05	< 0.05	< 0.05	0.46
17 Oct 79	< 0.05	< 0.05	< 0.05	0.08	0.55
15 Nov 79	< 0.05	< 0.05	< 0.05	0.10	0.56
17 Dec 79	< 0.05	< 0.05	< 0.05	0.18	0.68
7 Feb 80	< 0.05	< 0.05	0.69	0.06	0.53
27 Feb 80	0.05	0.05	1.08	0.05	0.30
10 Apr 80	0.06	0.06	0.30	0.06	0.49
23 May 80	0.05	0.05	0.22	< 0.05	0.19
12 Jun 80	0.06	0.06	0.12	< 0.05	0.14

TABLE 2

RATTLESDNAKE RESERVOIR: CONCENTRATIONS OF PLANT GROWTH-PROMOTING NUTRIENTS

Date of sample	Ortho-phosphate (as mg/l P)	Total phosphate (as mg/l P)	Nitrate-nitrite (as mg/l N)	Ammonia (as mg/l N)	Total Kjeldahl Nitrogen (as mg/l N)
20 Jan 78	3.36	3.40	7.79	0.38	1.09
23 Feb 78	3.92	4.02	9.45	0.07	1.81
16 Mar 78	4.20	4.22	2.79	0.25	2.75
19 Apr 78	4.12	4.58	8.58	0.12	2.51
24 May 78	2.09	2.24	6.90	0.28	3.35
14 Jun 78	1.40	1.43	4.46	1.00	3.23
19 Jul 78	0.39	0.51	1.00	0.10	1.45
15 Aug 78	0.39	0.46	0.82	0.10	1.29
25 Sep 78	0.14	0.37	< 0.05	0.05	1.21
19 Oct 78	0.49	0.96	0.49	0.17	1.08
29 Nov 78	5.15	5.60	10.60	0.07	1.69
15 Dec 78	5.98	6.12	14.10	0.22	1.93
19 Jan 79	5.90	6.20	14.05	< 0.05	1.46
15 Feb 79	6.75	6.77	14.00	0.44	1.96
15 Mar 79	6.45	6.46	14.20	0.13	2.25

TABLE 2 (continued)

RATTLESNAKE RESERVOIR: CONCENTRATIONS OF PLANT GROWTH-PROMOTING NUTRIENTS

Date of sample	Ortho-phosphate (as mg/l P)	Total Phosphate (as mg/l P)	Nitrate-nitrite (as mg/l N)	Ammonia (as mg/l N)	Total Kjeldahl Nitrogen (as mg/l N)
14 Apr 79	3.42	3.60	8.73	0.39	1.68
17 May 79	1.97	2.10	6.49	0.40	1.47
19 Jun 79	1.05	1.09	1.61	0.37	1.20
26 Jul 79	0.88	0.93	0.11	0.39	1.38
15 Aug 79	0.86	0.95	0.39	0.22	1.30
10 Sep 79	1.03	1.07	1.02	0.22	1.30
17 Oct 79	2.63	2.68	3.78	0.40	1.58
15 Nov 79	3.18	3.30	6.10	0.12	1.14
17 Dec 79	1.05	1.06	5.23	0.06	1.06
7 Feb 80	3.35	3.40	6.93	0.06	1.61
27 Feb 80	2.12	2.18	5.80	< 0.05	1.03
10 Apr 80	0.06	0.08	0.30	0.06	0.49
23 May 80	< 0.05	< 0.05	0.22	< 0.05	0.19
12 Jun 80	0.06	0.06	0.12	< 0.05	0.14

TABLE 3

SAND CANYON RESERVOIR: CONCENTRATIONS OF PLANT GROWTH-PROMOTING NUTRIENTS

Date of sample	Ortho-phosphate (as mg/l P)	Total Phosphate (as mg/l P)	Nitrate-nitrite (as mg/l N)	Ammonia (as mg/l N)	Total Kjeldahl Nitrogen (as mg/l N)
20 Jan 78	2.77	2.77	4.58	0.36	1.03
23 Feb 78	1.18	1.39	3.08	0.05	1.55
16 Mar 78	1.39	1.55	11.05	0.06	2.91
19 Apr 78	2.10	2.14	6.80	0.05	0.88
24 May 78	4.90	5.07	10.09	0.36	1.82
14 Jun 78	3.74	3.89	8.71	0.27	2.83
19 Jul 78	1.29	1.44	4.99	0.80	3.80
15 Aug 78	2.37	2.50	5.74	0.65	3.10
25 Sep 78	5.56	9.33	9.03	0.54	4.14
19 Oct 78	6.81	8.89	7.45	0.57	3.39
29 Nov 78	7.90	8.08	10.10	0.73	1.93
15 Dec 78	7.27	7.35	11.00	1.10	2.41
19 Jan 79	4.24	5.35	5.92	0.98	2.65
15 Feb 79	3.41	3.56	5.35	1.00	2.39
15 Mar 79	4.90	5.15	10.40	0.25	2.50

TABLE 3 (Continued)

SAND CANYON RESERVOIR: CONCENTRATIONS OF PLANT GROWTH-PROMOTING NUTRIENTS

Date of sample	Ortho-phosphate (as mg/l P)	Total Phosphate (as mg/l P)	Nitrate-nitrite (as mg/l N)	Ammonia (as mg/l N)	Total Kjeldahl Nitrogen (as mg/l N)
14 Apr 79	4.28	4.50	8.90	0.37	2.39
17 May 79	5.40	5.46	10.47	0.49	1.72
19 Jun 79	6.48	6.78	12.14	0.52	1.94
26 Jul 79	7.46	7.46	8.18	0.73	3.01
15 Aug 79	5.06	5.24	8.42	0.60	2.96
10 Sep 79	3.18	3.23	5.18	0.51	1.77
17 Oct 79	3.90	3.90	2.92	0.58	1.61
15 Nov 79	3.29	3.38	1.02	0.42	1.64
17 Dec 79	6.96	7.10	8.54	0.49	1.96
2 Feb 80	2.30	2.37	7.38	0.14	1.52
10 Apr 80	4.82	4.83	11.71	0.65	1.85
23 May 80	3.91	4.01	7.82	0.48	1.88
12 Jun 80	2.78	3.61	8.68	0.31	1.55

TABLE 4

SUMMARY OF PLANT GROWTH-PROMOTING NUTRIENTS IN SANTIAGO, RATTLESNAKE AND SAND CANYON RESERVOIRS

Nutrient:	Santiago Reservoir		Rattlesnake Reservoir		Sand Canyon Reservoir	
	Mean	Range	Mean	Range	Mean	Range
Ortho-phosphate (mg/l P)	0.10	< 0.05-0.76	2.49	< 0.05-6.75	4.13	1.18-7.90
Total phosphate (mg/l P)	0.17	< 0.05-1.23	2.61	< 0.05-6.77	4.49	1.38-9.33
Nitrate-nitrite (mg/l N)	0.25	< 0.05-1.21	5.38	< 0.05-14.10	7.44	1.02-12.14
Ammonia (mg/l N)	0.07	< 0.05-0.18	0.22	< 0.05-1.00	0.48	< 0.05-1.10
TKN (mg/l N)	0.60	0.11-2.63	1.54	0.14-3.35	2.17	0.88-4.14

TABLE 5

SANTIAGO RESERVOIR: CONCENTRATIONS OF HEAVY METALS

Date of sample	Lead (μg/l)	Copper (μg/l)	Zinc (μg/l)	Mercury (μg/l)	Cadmium (μg/l)	Chromium (μg/l)
20 Jan 78	< 20	< 20	< 20	1.0	< 10	< 5
23 Feb 78	< 20	< 20	< 20	< 0.5	< 10	< 5
16 Mar 78	< 20	< 20	< 20	< 0.5	< 10	< 5
19 Apr 78	< 20	< 20	< 20	< 0.5	< 10	6
24 May 78	< 20	< 20	< 20	< 0.5	< 10	< 5
14 Jun 78	< 20	< 20	< 20	< 0.5	< 10	< 5
19 Jul 78	< 20	< 20	< 20	< 0.5	< 10	< 5
18 Aug 78	< 20	< 20	< 20	----	< 10	---
25 Sep 78	< 20	< 20	< 20	----	< 10	---
19 Oct 78	< 20	< 20	< 20	----	< 10	---
29 Nov 78	< 20	< 20	< 20	----	< 10	< 5
15 Dec 78	< 20	< 20	< 20	< 0.5	< 10	< 5
19 Jan 79	< 20	< 20	< 20	< 0.5	< 10	---
15 Feb 79	< 20	< 20	< 20	< 0.5	< 10	< 5
15 Mar 79	< 20	< 20	< 20	< 0.5	< 10	---
14 Apr 79	< 20	< 20	< 20	< 0.5	< 10	< 5
8 May 79	< 20	< 20	< 20	< 0.5	< 10	< 5
19 Jun 79	< 20	< 20	< 20	< 0.5	< 10	< 5
26 Jul 79	< 20	< 20	< 20	< 0.5	< 10	< 5
15 Aug 79	< 20	< 20	< 20	< 0.5	< 10	< 5
10 Sep 79	< 20	< 20	< 20	< 0.5	< 10	< 5
17 Oct 79	< 20	< 20	< 20	< 0.5	< 10	< 5

TABLE 5 (continued)

SANTIAGO RESERVOIR: CONCENTRATIONS OF HEAVY METALS

Date of sample	Lead (μg/l)	Copper (μg/l)	Zinc (μg/l)	Mercury (μg/l)	Cadmium (μg/l)	Chromium (μg/l)
15 Nov 79	< 20	< 20	< 20	< 0.5	< 10	< 5
17 Dec 79	< 20	< 20	< 20	< 0.5	< 10	< 5
7 Feb 80	< 20	< 20	< 20	< 0.5	< 10	< 5
27 Feb 80	< 20	< 20	< 20	< 0.5	< 10	< 5
10 Apr 80	< 20	< 20	< 20	< 0.5	< 10	< 5
23 May 80	< 20	< 20	< 20	< 0.5	< 10	< 5
16 Jun 80	< 20	< 20	< 20	< 0.5	< 10	< 5

TABLE 6

RATTLESNAKE RESERVOIR: CONCENTRATIONS OF HEAVY METALS

Date of sample	Lead (μg/l)	Copper (μg/l)	Zinc (μg/l)	Mercury (μg/l)	Cadmium (μg/l)	Chromium (μg/l)
20 Jan 78	< 20	< 20	< 20	< 0.5	< 10	< 5
23 Feb 78	< 20	< 20	< 20	12.7	< 10	< 5
16 Mar 78	< 20	< 20	< 20	< 0.5	11	< 5
19 Apr 78	29	< 20	< 20	< 0.5	< 10	< 5
24 May 78	< 20	< 20	< 20	< 0.5	< 10	< 5
14 Jun 78	< 20	< 20	< 20	< 0.5	< 10	< 5
19 Jul 78	< 20	< 20	< 20	< 0.5	< 10	< 5
18 Aug 78	< 20	< 20	< 20	< 0.5	< 10	< 5
25 Sep 78	56	< 20	< 20	----	< 10	----
19 Oct 78	< 20	< 20	< 20	----	< 10	----
29 Nov 78	< 20	< 20	< 20	----	< 10	----
15 Dec 78	< 20	< 20	< 20	< 0.5	< 10	----
19 Jan 79	< 20	< 20	< 20	< 0.5	< 10	< 5
15 Feb 79	< 20	< 20	< 20	< 0.5	< 10	< 5
15 Mar 79	< 20	< 20	< 20	< 0.5	< 10	< 5
14 Apr 79	< 20	< 20	< 20	< 5.0	< 10	< 5
8 May 79	< 20	< 20	< 20	< 0.5	< 10	< 5
19 Jun 79	< 20	< 20	< 20	< 0.5	< 10	< 5
26 Jul 79	< 20	< 20	< 20	< 0.5	< 10	< 5
15 Aug 79	< 20	< 20	< 20	< 0.5	< 10	< 5
10 Sep 79	< 20	< 20	< 20	< 0.5	< 10	< 5
17 Oct 79	< 20	< 20	< 20	< 0.5	< 10	< 5

TABLE 6 (continued)

RATTLESNAKE RESERVOIR: CONCENTRATIONS OF HEAVY METALS

Date of sample	Lead (μg/l)	Copper (μg/l)	Zinc (μg/l)	Mercury (μg/l)	Cadmium (μg/l)	Chromium (μg/l)
15 Nov 79	< 20	< 20	< 20	< 0.5	< 10	< 5
17 Dec 79	< 20	< 20	< 20	< 0.5	< 10	< 5
7 Feb 80	< 20	< 20	< 20	< 0.5	< 10	< 5
27 Feb 80	< 20	< 20	< 20	< 0.5	< 10	< 5
10 Apr 80	< 20	< 20	< 20	< 0.5	< 10	< 5
23 May 80	< 20	< 20	< 20	< 0.5	< 10	< 5
12 Jun 80	< 20	< 20	< 20	< 0.5	< 10	< 5

TABLE 7

SAND CANYON RESERVOIR: CONCENTRATIONS OF HEAVY METALS

Date of sample	Lead (μg/l)	Copper (μg/l)	Zinc (μg/l)	Mercury (μg/l)	Cadmium (μg/l)	Chromium (μg/l)
20 Jan 78	< 20	< 20	< 20	< 0.5	< 10	< 5
23 Feb 78	< 20	< 20	< 20	0.7	< 10	7
16 Mar 78	< 20	< 20	< 20	< 0.5	< 10	9
19 Apr 78	< 20	< 20	< 20	< 0.5	< 10	< 5
24 May 78	< 20	< 20	26	< 0.5	< 10	< 5
14 Jun 78	< 20	< 20	< 20	< 0.5	< 10	< 5
19 Jul 78	< 20	< 20	< 20	< 0.5	< 10	< 5
15 Aug 78	< 20	< 20	< 20	< 0.5	< 10	< 5
25 Sep 78	< 20	< 20	< 20	----	< 10	---
19 Oct 78	< 20	< 20	< 20	----	< 10	---
29 Nov 78	< 20	< 20	< 20	< 0.5	< 10	---
15 Dec 78	< 20	< 20	< 20	< 0.5	< 10	---
19 Jan 79	----	< 20	< 20	< 0.5	< 10	---
15 Feb 79	< 20	< 20	< 20	< 0.5	< 10	---
15 Mar 79	< 20	< 20	< 20	----	< 10	---
14 Apr 79	< 20	< 20	< 20	< 0.5	< 10	< 5
8 May 79	< 20	< 20	< 20	< 0.5	< 10	< 5
19 Jun 79	< 20	< 20	< 20	< 0.5	< 10	< 5
26 Jul 79	< 20	< 20	< 20	< 0.5	< 10	< 5
15 Aug 79	< 20	< 20	< 20	< 0.5	< 10	< 5
10 Sep 79	< 20	< 20	< 20	< 0.5	< 10	< 5
17 Oct 79	< 20	< 20	< 20	< 0.5	< 10	< 5

TABLE 7 (continued)

SAND CANYON RESERVOIR: CONCENTRATIONS OF HEAVY METALS

Date of sample	Lead (μg/l)	Copper (μg/l)	Zinc (μg/l)	Mercury (μg/l)	Cadmium (μg/l)	Chromium (μg/l)
15 Nov 79	< 20	< 20	< 20	< 0.5	< 10	< 5
17 Dec 79	< 20	< 20	< 20	< 0.5	< 10	< 5
7 Feb 80	< 20	< 20	< 20	< 0.5	< 10	< 5
10 Apr 80	< 20	< 20	< 20	< 0.5	< 10	< 5
23 May 80	< 20	< 20	< 20	< 0.5	< 10	< 5
16 Jun 80	< 20	< 20	< 20	< 0.5	< 10	< 5

TABLE 8

PLANT GROWTH-PROMOTING NUTRIENTS IN THE INFLOW STREAMS TO SANTIAGO, RATTLESNAKE AND SAND CANYON RESERVOIRS

	Ortho-phosphate (as mg/l P)		Total Phosphate (as mg/l P)		Nitrate-nitrite (as mg/l N)		Ammonia (as mg/l N)		Total Kjeldahl Nitrogen (as mg/l N)	
Reservoir	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Santiago	0.09-0.12	0.11	0.11-0.16	0.14	1.27-1.29	1.28	0.05-0.09	0.06	0.86-2.33	1.58
Rattlesnake	0.32*	—	0.59*	—	0.74*	—	0.05*	—	1.68*	--
Sand Canyon	0.26-5.90	1.77	0.29-5.62	1.73	0.42-6.64	2.0	0.05-0.84	0.19	2.91-5.32	2.41

*Based on a single sampling

TABLE 9

HEAVY METAL CONTENT IN THE INFLOW STREAMS TO SANTIAGO, RATTLESNAKE AND SAND CANYON RESERVOIRS.

	Lead (μg/l)		Copper (μg/l)		Zinc (μg/l)		Mercury (μg/l)		Cadmium (μg/l)		Chromium (μg/l)	
Inflow Stream	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Santiago	< 20-119	53	< 20-140	60	7-193	71		0.5	< 10-< 10	< 10	< 5-160	56
Rattlesnake	184*	--	230*	--	367*	--	1*	--	46*	--	280*	--
Sand Canyon	< 20-196	43	< 20-145	33	< 20-160	57	< 1.0-< 1.0	< 1.0	< 10-< 10	< 10	14-130	49

*Based on a single sampling

TABLE 10

PLANT GROWTH-PROMOTING NUTRIENTS IN THE EFFLUENT FROM THE MICHELSON PLANT OF THE IRVINE RANCH WATER DISTRICT.

Ortho-phosphate (as mg/l P)		Total Phosphate (as mg/l P)		Nitrate-Nitrite (as mg/l N)		Ammonia (as mg/l N)		Total Kjeldahl Nitrogen (as mg/l N)	
Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
not measured	—	not measured	—	1.1-26.50	15.30	0.0-18.6	1.6	0.0-28.7	3.2

TABLE 11

PLANT GROWTH-PROMOTING NUTRIENTS IN THE OUTFLOWS FROM SAND CANYON AND RATTLESNAKE RESERVOIRS

	Ortho-phosphate (as mg/l P)		Total Phosphate (as mg/l P)		Nitrate-Nitrite (as mg/l N)		Ammonia (as mg/l N)		Total Kjeldahl Nitrogen (as mg/l N)	
Location	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Rattlesnake	3.83-8.34	6.78	3.75-8.14	4.57	10.05-14.30	12.37	0.30-1.40	0.73	1.71-3.36	1.90
Sand Canyon	1.26-5.53	3.53	1.33-5.21	3.37	2.81-10.20	5.82	0.13-1.02	0.43	1.54-3.56	2.51

TABLE 12

HEAVY METAL CONTENT OF THE OUTFLOWS FROM SAND CANYON AND RATTLESNAKE RESERVOIRS

	Lead (µg/l)		Copper (µg/l)		Zinc (µg/l)		Mercury (µg/l)		Cadium (µg/l)		Chromium (µg/l)	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Rattlesnake	<20- <20	<20	<20- <20	<20	<20-26	23.7	<0.5- <0.5	<0.5	<10- <10	<10	8*	--
Sand Canyon	<20- <20	<20	<20- 31	22	<20-26	21.5	<0.5- <0.5	<0.5	<10-<<10	<10	19-53	31

* Based on a single sample

terms of algal growth-promoting nutrients (Tables 1, 2, 3, 4) there is a general sequence of increasing nutrient status: (1) Santiago Reservoir, (2) Rattlesnake Reservoir, (3) Sand Canyon Reservoir. It would appear that this increasing was due simply to the reclaimed water being stored in Rattlesnake and Sand Canyon Reservoirs.

In terms of heavy metals (Tables 5, 6, 7), although there are variations in concentration, the levels are always low, usually below detection limits. The local geological strata are metaliferous and there was therefore a real question as to whether heavy metal inputs to the three reservoirs might preclude the use of the stored water for irrigation purposes. Also, as the levels of heavy metals for the effluent from the Michelson Water Reclamation Plant were not known, there was a further cause for concern. The levels of heavy metals in the input streams (Table 9) are certainly higher than for the water stored in the reservoirs but this input is diluted sufficiently by the other water sources to remove any potential difficulty for use in irrigation.

CHAPTER VI

WATER QUALITY STUDIES OF SANTIAGO, RATTLESNAKE AND SAND CANYON RESERVOIRS: ALGAL POPULATIONS

Introduction

As algal populations are the primary producers in all three reservoirs and as algae are the plants most responsive to changes in nutrient status, it was thought initially that monthly quantified sampling of the phytoplankton populations would provide insight into the effects of reclaimed water on reservoir biology.

Methods

From a composite water sample collected from the reservoir, an aliquot was removed immediately and fixative (formalin) added. The fixed sample was allowed to settle in a settling chamber. This was then examined microscopically and the algae present in 1 ml were identified and quantified.

Results

Despite the effort which was expended on analyses of the algal flora present in the three reservoirs, the results are quantitatively meaningless. A general pattern was, however, present in all three reservoirs, irrespective of whether reclaimed water was introduced or not. The general pattern was as follows:

1. A winter flora, dominated by *Platymonas* sp., *Rhodomonas* sp., *Scenedesmus* sp., *Pediastrum* sp., and *Westiella* sp. This occurs usually between early December and late March.

2. A rather short-lived diatom population dominated by *Cyclotella* sp., various species of naviculoid diatoms and *Fragilaria* sp. This diatom flora is rather short-lived, persisting only until about early May.
3. With the onset of higher temperatures and higher light intensities, the algal population is soon dominated by blue-green algae such as *Anabaena* sp. *Microcystis* sp. and, in some years, with a high preponderance of *Oscillatoria* sp. This blue-green algal flora persists until the early fall.
4. During the late summer and early fall, the planktonic algal flora diminishes and the major and most obvious algal populations are composed of species of *Rhizoclonium* and *Oedogonium*. This last population persists until the final breakdown of the summer stratification, whereupon it is replaced by the typical winter planktonic population, listed in (1) above.

Discussion

The realisation that analyses of the algal populations present in the three reservoirs gave little information of significance in this study of the effects of reclaimed water on the behavior of reservoirs was a grave disappointment. The seasonal pattern observed here and in other reservoirs of southern California, irrespective of whether they received reclaimed water or not was similar. Furthermore, the quantitative estimates of species present showed wild fluctuations.

The results obtained are probably explainable on two counts. Probably the most important factor was the variation in chemical parameters, particularly of those components which stimulate algal growth, which are extremely wide (see Chapter V). A second element which had not been considered prior to the present investigation was that of predation. It had not been considered that predation was of consequence, so that no attempt had been made to consider the total ecosystem. This was obviously a mistake in primary planning although casual observations during the course of the investigation indicated that predation of algae was of much greater significance than had been anticipated. It has truly been said that hindcasting is easier than forecasting and this is borne out in the present study. Predation is obviously of considerable importance in any consideration of the algal populations present in a reservoir, whether or not it receives reclaimed water. A recent study (Leah et al., 1980) showed that under hyper-eutrophic conditions, the relationship between algae and their predators was controlled by fish grazing on the algal predators, although it was not possible to confirm this under the conditions of the present study.

The final matter to be discussed relates to the blue-green algal population which develops in all three reservoirs during the summer conditions of warmer temperatures and higher light intensities. This population was always present, irrespective of the addition of reclaimed water or not, although it never develped into a massive bloom such as is found in many bodies of water of high trophic status. In Lake Perris, for example (Elder et al., 1979), the massive bloom of blue-green algae in the early fall was a consequence of nitrogen limitation associated with considerable quantities of phosphorus. Although levels of ammonia and nitrate/nitrite in all three reservoirs fell to extremely low levels in the summer and early fall, there was always a considerable amount of organic nitrogen present. It is hypothesized that this organic nitrogen was constantly being broken down and providing just sufficient inorganic nitrogen to prevent the development of a massive blue-green algal bloom.

CHAPTER VII

WATER QUALITY STUDIES OF SANTIAGO, RATTLESNAKE AND SAND CANYON RESERVOIRS: DISSOLVED AND SUSPENDED SOLIDS

Introduction

Normally, dissolved and suspended solids are each measured as a total quantity. In the case of suspended solids, this is not enough in that it gives no indication of the size of the particles involved. Fractionation of the suspended solid loading gives a detailed indication of the type of material involved and ultimately of its origin.

Methods

The basic procedure employed during the present investigation was to pass an aliquot through a series of filters and calculate the sizes involved by weighing and subtraction. The filters used were as follows:

1. 30-mesh, with a pore size of approximately 600 μm,
2. 200-mesh, with a pore size of approximately 75 μm,
3. fiber-glass filter, with a pore size of 1 μm,
4. Millepore filter 0.22 μm.

Results

The level of dissolved solids was considered to be that material which passed an 0.22 μm filter. The results of fractionation of suspended solids and the levels of suspended solids are shown for Santiago Reservoir (Table 13), Rattlesnake Reservoir (Table 14) and Sand Canyon Reservoir (Table 15), with a summary table (Table 16) of the average levels of dissolved solids for the three reservoirs.

TABLE 13

SANTIAGO RESERVOIR: DISSOLVED AND SUSPENDED SOLIDS

Date of Sample	Total dissolved solids (in mg/l)	Total suspended solids (in mg/l)	Fractionation of suspended solids (in mg/l)			
			0.22-1.0 μm	1-75 μm	75-600 μm	> 600 μm
8 May 79	501	4.98	0.37	4.02	0.44	0.15
19 Jun 79	515	3.97	0.21	3.61	0.07	0.08
26 Jul 79	517	7.65	0.19	7.37	0.02	0.07
14 Aug 79	525	10.14	0.12	6.95	1.85	1.22
10 Sep 79	522	6.95	0.11	6.30	0.19	0.35
17 Oct 79	543	4.14	0.02	3.70	0.37	0.05
15 Nov 79	596	4.87	0.26	4.44	0.05	0.12
17 Dec 79	538	8.86	0.35	8.27	0.15	0.09
7 Feb 80	463	7.19	0.32	6.64	0.22	0.01
27 Feb 80	387	8.37	4.56	3.17	0.33	0.31
10 Apr 80	505	6.25	1.67	3.22	1.25	0.12
23 May 80	534	4.51	0.89	3.37	0.17	0.08
12 Jun 80	537	3.28	0.11	2.32	0.78	0.07

TABLE 14

RATTLESNAKE RESERVOIR: DISSOLVED AND SUSPENDED SOLIDS (mg/l)

Date of sample	Total dissolved solids (in mg/l)	Total suspended solids (in mg/l)	Fractionation of suspended solids (in mg/l)			
			0.22-1.0 μm	1-75 μm	75-600 μm	> 600 μm
15 Nov 77	892	13.52	0.02	7.19	6.29	0.02
13 Dec 77	940	23.57	15.69	4.26	3.58	0.04
10 Jan 78	873	18.02	15.37	2.63	0.02	0.00
23 Feb 78	907	7.79	3.75	3.99	0.05	0.00
16 Mar 78	940	4.36	2.19	0.92	0.04	4.36
19 Apr 78	---	----	----	----	----	----
24 May 78	902	7.50	0.98	6.37	0.10	0.05
14 Jun 78	---	----	----	----	----	----
19 Jul 78	836	17.45	0.75	16.37	0.27	0.06
18 Aug 78	799	21.31	0.63	19.62	0.89	0.17
25 Sep 78	746	26.92	0.84	24.49	0.76	0.83
19 Oct 78	773	26.46	0.96	23.76	0.82	0.92
29 Nov 78	796	23.56	1.17	21.30	0.00	1.09
15 Dec 78	825	20.01	0.87	19.14	0.00	0.00
19 Jan 79	684	10.56	1.57	8.93	0.04	0.02
15 Feb 79	676	5.90	2.79	2.17	0.05	3.68

TABLE 14 (continued)

RATTLESNAKE RESERVOIR: DISSOLVED AND SUSPENDED SOLIDS (mg/l)

Date of sample	Total dissolved solids (in mg/l)	Total suspended solids (in mg/l)	Fractionation of suspended solids (in mg/l)			
			0.22-1.0 µm	1-75 µm	75-600 µm	> 600 µm
15 Mar 79	747	7.99	1.93	4.35	0.04	1.67
14 Apr 79	795	10.63	0.84	8.69	0.37	0.73
8 May 79	839	16.50	0.65	14.74	0.63	0.48
19 Jun 79	638	28.39	0.79	26.82	0.67	0.11
26 Jul 79	613	62.42	0.34	59.78	1.25	1.05
14 Aug 79	622	29.13	0.46	28.34	0.27	0.06
10 Sep 79	693	32.29	0.82	29.17	0.98	1.32
17 Oct 79	768	20.60	0.96	16.09	0.44	3.11
15 Nov 79	757	27.56	0.77	25.49	1.24	0.06
17 Dec 79	693	19.28	2.89	15.72	0.36	0.31
7 Feb 80	691	30.34	21.65	8.15	0.50	0.04
27 Feb 80	603	37.08	24.29	11.13	0.71	0.95
10 Apr 80	717	24.78	11.17	13.29	0.28	0.04
23 May 80	728	19.13	0.83	17.70	0.26	0.34
12 Jun 80	593	13.65	0.65	12.38	0.20	0.42

TABLE 15

SAND CANYON RESERVOIR: DISSOLVED AND SUSPENDED SOLIDS (mg/l)

Date of sample	Total dissolved solids (in mg/l)	Total suspended solids (in mg/l)	Fractionation of suspended solids (in mg/l)			
			0.22-1.0 μ m	1-75 μ m	75-600 μ m	< 600 μ m
15 Nov 77	1149	21.26	1.95	15.79	0.27	3.25
13 Dec 77	1197	13.39	4.54	7.32	2.51	0.02
10 Jan 78	556	166.74	81.95	2.53	45.39	36.87
23 Feb 78	414	471.32	20.76	4.84	76.18	369.54
16 Mar 78	520	20.06	10.27	5.13	2.65	20.06
19 Apr 78	---	---	---	---	---	---
24 May 78	653	18.64	1.53	15.37	1.72	0.02
14 Jun 78	---	---	---	---	---	---
19 Jul 78	892	19.0	2.09	16.19	0.65	0.07
18 Aug 78	878	22.49	1.82	17.32	1.37	1.98
25 Sep 78	849	23.66	1.79	19.61	1.89	0.37
19 Oct 78	825	23.86	1.60	18.34	2.13	0.79
29 Nov 78	800	16.01	1.21	16.42	2.00	2.01
15 Dec 78	893	14.36	0.92	12.30	1.09	0.05
19 Jan 79	599	17.47	4.38	8.42	0.98	3.69
15 Feb 79	567	11.93	5.72	2.84	1.23	2.14

TABLE 15 (continued)

SAND CANYON RESERVOIR: DISSOLVED AND SUSPENDED SOLIDS

Date of sample	Total dissolved solids (in mg/1)	Total suspended solids (in mg/1)	Fractionation of suspended solide (in mg/1)			
			0.22-1.0 μm	1-75 μm	75-600 μm	> 600 μm
15 Mar 79	833	8.10	2.93	3.34	0.76	1.07
14 Apr 79	840	6.20	1.10	4.50	0.52	0.08
8 May 79	844	4.98	0.85	3.54	0.44	0.15
19 Jun 79	871	6.45	1.37	4.83	0.23	0.02
26 Jul 79	891	9.34	0.92	7.70	0.65	0.07
15 Aug 79	961	14.86	1.62	11.05	1.53	0.66
10 Sep 79	949	18.68	1.17	15.99	0.68	0.84
17 Oct 79	942	29.18	0.98	25.90	1.90	0.40
15 Nov 79	928	19.60	0.71	18.33	0.52	0.04
17 Dec 79	962	39.46	1.92	37.48	0.02	0.04
7 Feb 80	590	42.67	14.76	24.05	1.59	2.27
27 Feb 80	501	35.29	10.32	9.41	5.04	10.52
10 Apr 80	805	11.21	2.79	4.89	2.31	1.22
23 May 80	829	14.82	1.68	11.75	1.05	0.34
12 Jun 80	824	10.12	1.43	7.33	1.02	0.34

TABLE 16

SUMMARY OF LEVELS OF TOTAL DISSOLVED SOLIDS IN SANTIAGO, RATTLESNAKE AND SAND CANYON RESERVOIRS (in mg/l).

RESERVOIR	RANGE OF TDS	MEAN VALUE
Santiago	387 - 596	514
Rattlesnake	593 - 940	761
Sand Canyon	520 - 1197	805

Discussion

Suspended solids in water are derived from various sources. The decision in the present investigation to fractionate the suspended solids by sequential filtration gave valuable information on the sources of this material. This is particularly significant when the use of reclaimed water stored in reservoirs has been troubled by technical problems resulting from blockage of equipment by suspended material. Furthermore, the usage of water of high TDS for irrigation purposes has also posed problems.

Considering first the level of dissolved solids, there is a gradient between the three reservoirs with the highest level in Sand Canyon Reservoir, a lesser amount in Rattlesnake Reservoir and the lowest amount in Santiago Reservoir. This gradient is related directly to the amount of reclaimed water entering each body of water.

Considering next the level of suspended solids as a total, the value fluctuates enormously from month to month and in reservoir to reservoir. This is because the various components of the suspended solids differ in their seasonal characteristics. The material in the range 0.22 - 1.0 µm represents sediment and the highest levels occur only immediately after heavy rains, in all three reservoirs. Levels of suspended solids of this size range never exceed 1.0 mg/l except following rains in Santiago and Rattlesnake Reservoirs, although this is not so with Sand Canyon Reservoir. It might appear therefore that the higher levels (only of the order of one to two mg/l) were either due directly to the reclaimed water entering this reservoir to the greatest extent or due to the breakdown products of greater algal growth resulting from that reclaimed water addition. The suspended solids of the size range 1.0 - 75.0 µm relate to the planktonic algae. The levels in this range are highest during the summer months when algal growth is at its maximum and show clearly the greater planktonic algal growth resulting from the inputs of reclaimed water. Thus, in this size range the levels for Santiago Reservoir are the lowest of the three reservoirs and highest in Sand Canyon Reservoir. Suspended solids in the size range 75.0 - 600 μm do not encompass a single biological component but consist of larger (filamentous) algae when these were present in the water column, species of zooplankton and smaller pieces of vegetable detritus which were washed into the reservoirs after heavy rains. The levels are lowest for Santiago Reservoir although it is not possible to give any detailed analysis for this size range because of the different components potentially involved. Suspended solids greater than 600 μm are almost exclusively derived from larger vegetable debris. The amounts of this which pass into a reservoir from its watershed depend on the nature of the latter and climatic conditions during preceding years. The winters of 1976/76 and 1976/77 were relatively dry whereas the rainfall during the winter of 1977/78 (when this investigation commenced) were much larger than normal. The highest levels of suspended solids in the present size range were recorded at Sand Canyon Reservoir in early 1978. The watershed or this reservoir contains a considerable amount of grassland (used for cattle grazing) and the rains of 1977/78 brought down quantities of accumulated vegetable debris from preceding years growth. The watersheds of Santiago Reservoir and Rattlesnake Reservoir do not contain the same amount of grassland but rather are covered by shrubby chaparral vegetation.

Fractionation of the suspended solids proved to be a most valuable method by which to study this feature, critical in terms of the use of stored reclaimed water.

CHAPTER VIII

WATER QUALITY STUDIES OF SANTIAGO, RATTLESNAKE AND SAND CANYON RESERVOIRS: ALGAL GROWTH POTENTIAL.

Introduction

The failure of determinations of algal popultions to illustrate the differences between reservoirs receiving reclaimed from those which did not (Chapter VI), placed even more emphasis on the determinations of algal growth potential. This procedure gives an indication of the maximum possible degree of algal growth in any body of water.

There has been a considerable increase in understanding eutrophication during the past 25 years. This has been due largely to better analytical procedures now available for such basic nutrients as phosphate and nitrate and to more complete knowledge of the macronutrients and micronutrients (both organic and inorganic) necessary for algal growth. But, it is still not possible to predict the amount of algal growth which will occur in a water sample however complete the list of growth-promoting materials which can be demonstrated to be present or estimated quantitatively. Because of this problem, a Joint Industry/Government Task Force on Eutrophication was established in the 1960's and quickly recognized that acceptable standardized algal growth tests must be developed as a tool to be used in controlling eutrophication. Algal assays had been used extensively for specific projects on previous occasions by many investigators, but these assays offered no basis for comparison because of lack of standardization. In February 1969, the Joint Task Force published the Provisional Algal Assay Procedure which consisted of three standard tests. After some years of research and testing, it was agreed that one procedure, the so-called "bottle test", was sufficiently reliable for general use, and a basic description was published (U.S. Environmental Protection Agency, 1971). Subsequently, the procedure was included provisionally in "Standard Methods" (American Public Health Association, 1975), and recently a more comprehensive and specific account of the bottle test was published (U.S. Environmental Protection Agency, 1978). Neither of the two other tests proposed initially has been developed sufficiently for general application, so that in most instances the term "algal bioassay procedure" refers to what was termed originally the "bottle test."

Methods

The procedure depends on a single basic premise. If one cannot predict the amount of algal growth which will occur in a water sample from a knowledge of the chemical components present, a water sample can be assayed by measuring the growth of a standard species of alga in it. The growth of an alga depends on the interaction of many biochemical processes, all dependent to a greater or lesser extent on the organic and inorganic components present in the medium in which it occurs. In other words, the growth of a standard species is used as the basis for comparison between waters, and the growth in water samples is compared with the growth in a standard algal growth medium. Although three species were designated originally as test organisms for use in freshwater, most subsequent work has entailed only one of these, *Selenastrum capricornutum* Printz, because this species has been found relatively easy to handle and count, and both tolerant and responsive to a wide range of conditions. There appears to be general agreement that this species can be used effectively in waters with a level of total dissolved solids less that 5,000 ppm. The standard algal medium (SAAM) used for the comparison of freshwaters has a nutrient status equivalent to high quality secondary sewage effluent.

This is not the place for detailed discussion of experimental procedures which are dealt with in detail elsewhere (U.S. Environmental Protection Agency, 1971; 1978; United States Geological Survey, 1977). In outline, the procedure consists of removing all indigenous organisms and suspended solids from a water sample and inoculating it with the standard test organism to an initial density of 10^6 cells per liter. The inoculated samples are then placed on an illuminated shaker table and subsequent growth of the test organism monitored by determining biomass at intervals. It is advisable to pass CO_2-enriched air through samples when high levels of algal growth occur. Photosynthesis removes CO_2, so that in waters of high nutrient status the algal population grows rapidly and a considerable amount of CO_2 will be eliminated. The consequence of this is that the growth rate will be reduced becaose of CO_2 limitation and the experiment will be prolonged. Even more important is the possible conversion of trace metals, such as iron and manganese, into insoluble forms at a pH above 9.0 and this could produce serious misinterpretations. A sample is deemed to have grown to maximum biomass when the increase is less than 5 percent per day. Monitoring can be carried out in various ways. A gravimetric method involving filtration and weighing is applicable only for waters of extremely high nutrient status in which very high cell densities develop, while the use of a hemocytometer slide to count the cells present is laborious and not particularly accurate. At the UCI Water Resources Laboratory, it has been found that the use of an electronic particle counter (Coulter Counter) is accurate and relatively economical in terms of time and effort. With this type of counter, it is possible to evaluate both total cell number and total cell volume.

Three replicates were prepared of each sample and in addition, as a control precedure to check that the inoculum of test organism was performing properly, a sample of standard artificial medium was also tested on each and every occasion, in triplicate.

Results

The determinations of algal growth potential in monthly samples from the three reservoirs are shown in Table 17.

Discussion

As might be expected from the great variation in chemical components which are plant growth-promoting in the three reservoirs (Chapter V), the algal growth potentials of the water also shows considerable variation (Table 17). However, the mean values for the three reservoirs show a consistent pattern. The water of Santiago Reservoir shows the lowest algal growth potential ($243 \pm 223 \times 10^6$ cells/l): this reservoir receives no reclaimed water. The level for Rattlesnake Reservoir is higher ($4036 \pm 1372 \times 10^6$ cells/l) while that for Sand Canyon Reservoir is highest ($8284 \pm 3946 \times 10^6$ cells/l) consistent with the amounts of reclaimed water received in the two last reservoirs.

The question then arises as to why the algal populations actually present in the reservoirs did not show a similar trend. The apparent answer is that the algal growth potential of the water represents the potential algal population which could be present while the population actually present represents the difference between the cells produced and those removed. Predation by copepods and cladocerans (which were frequently seen in Rattlesnake and Sand Canyon Reservoirs) is probably the answer, as discussed in Chapter VI.

TABLE 17

ALGAL GROWTH POTENTIAL OF THE WATERS OF SANTIGAO, RATTLESNAKE AND SAND CANYON RESERVOIRS (in 10^6 cells/l)

Date of sample	Santiago Reservoir	Rattlesnake Reservoir	Sand Canyon Reservoir
20 Jan 78	256	4623	14166
20 Feb 78	218	8360	9460
16 Mar 78	378	2660	8282
19 Apr 78	899	10161	3654
24 May 78	209	6460	18771
14 Jun 78	52	5269	5784
19 Jul 78	186	2805	8003
15 Aug 78	---	---	---
25 Sep 78	26	1316	3263
19 Oct 78	74	3303	5114
29 Nov 78	20	1993	1910
15 Dec 78	16	2856	7817
19 Jan 79	1037	4729	12600
15 Feb 79	23	5279	15236
15 Mar 79	58	5122	10210
14 Apr 79	325	4993	10021
8 May 79	173	3879	9981
19 Jun 79	82	2497	15936
26 Jul 79	115	2956	8356
15 Aug 79	74	1870	7923
10 Sep 79	39	1987	4597
17 Oct 79	124	2593	6714
15 Nov 79	375	3690	8946
17 Dec 79	836	6429	10110
Mean values	243±223	4036±1372	8284±3946

CHAPTER IX

GENERAL DISCUSSION

Little is known about the chemical and biological characteristics of shallow lakes or reservoirs and nothing is known of these when reclaimed water represents a major input. A recently-published text on the ecological effects of waste water (Welch, 1980) makes no mention whatsoever of reservoirs. The present study represents the first investigation of shallow lakes receiving reclaimed water.

The major problem with shallow lakes is that they are subject to considerable variations and this is doubly significant with impoundments receiving reclaimed water for storage. This variability is indicated in the chemical and biological studies of Santiago, Rattlesnake and Sand Canyon Reservoirs. The biological characteristics of any lake or reservoir are determined by the basic chemical parameters and in the three reservoirs under investigation, these are subject to wild fluctuations. These variations are basically due to the very different characteristics of the water entering. For Santiago Reservoir, the inputs are derived from direct precipitation, surface run-off and Colorado River water derived from the Metropolitan Water District. For Rattlesnake Reservoir, the inputs are derived from direct precipitation, surface run-off, water transferred from Santiago Reservoir by the Highline Canal and reclaimed water from the Michelson Reclamation Plant of the Irvine Ranch Water District. Finally, for Sand Canyon Reservoir, the inputs are derived from direct precipitation, surface run-off and reclaimed water. The major variable is the quantity of reclaimed water, with none entering Santiago Reservoir, some entering Rattlesnake Reservoir, and a considerable quantity entering Sand Canyon Reservoir. Water for use in irrigation is withdrawn from all three reservoirs.

Considering first the algal growth-promoting nutrients, the mean values for ortho-phosphate, total phosphate, nitrate/nitrite, ammonia and total organic nitrogen (TKN) are all higher for Sand Canyon Reservoir than for Rattlesnake and both are higher than for Santiago (Table 4). These values are obviously a consequence of the relative amounts of inputs of reclaimed water, because the levels of these nutrients in the inflow streams are all relatively low. The values for these algal growth-promoting nutrients are higher in the outflow water (Table 11) than for the total water column in the reservoirs because the outflow water is drawn from the lowermost levels in the reservoir. Accumulated organic material in bottom deposits regenerates nutrients and when stratified (a condition which persists for most of the annual cycle) these materials do not circulate throughout the water column.

Considering next the potentially toxic heavy metals, these never reach a critical level either in the reservoirs (ables 5, 6, 7, 8) or in the outflows (Table 12). The highest values during the present study were recorded for the input streams (Table 9) and this is a reflection of the metaliferous strata which occur in the watershed.

Considering next the measurements of algal growth potential (Table 17) these do not correlate directly with measurements of algal growth-promoting nutrients present in the reservoirs. This is to be expected in that algal growth is a reflection of the total nutrient content and the latter is subject to considerable fluctuation because of regeneration from bottom deposits as well as drawdown from the lower layers of the water column. However, if the values for the three bodies of water are averaged over the period of investigation, the algal growth potential shows a gradient: Sand Canyon Rattlesnake, Santiago. The algal growth potential for Santiago Reservoir could be taken as the normal for a local watershed without reclaimed water. The average value of the algal growth potential for Rattlesnake Reservoir is about 16 times greater than for Santiago while that for Sand Canyon Reservoir is 34 times higher.

It had been anticipated that there would be significant differences in algal populations between the three reservoirs, reflecting their different inputs of reclaimed water. That this was not so, considering the amount of time and effort which had been expended on identification and quantification of the algal populations, was a grave disappointment. Preliminary studies of the three reservoirs prior to the present study had given no indication that predation was of major consequence although indications of extensive predation were obtained during the present investigation in all three reservoirs. Thus measurements of algal populations alone are not enough. Measurement of algal growth potential indicates the potential algal population which could be present while measurement of the actual population represents the difference between cells produced and cells removed. Thus, an investigation of the impact of reclaimed water on the total ecosystem is what is required and this involves a considerable expenditure of funds, time and effort, which would probably not be justified.

Finally, the principal purpose of the present investigation was to consider the biological properties of the water impounded in Rattlesnake and Sand Canyon Reservoirs in terms of its use for irrigation purposes. In this regard, the two most significant parameters are:

1. The levels of dissolved solids which can set limits beyond which the water cannot be used for irrigation of particular crops.

2. The levels of suspended solids which affect the operation of sprinkler systems by clogging.

Considering first the variations in the levels of dissolved solids, these are a reflection, at any given time, of the quantities of water of the basic types which are filling the reservoir and of the amount of water being withdrawn for irrigation purposes. Maximum levels of total dissolved solids were recorded during the present investigation immediately prior to the onset of the winter rainy season while minimum levels occur towards the end (Table 16).

The levels of suspended solids show enormous variation in each reservoir from month to month (Tables 13, 14 and 15), because the various components which make up the load of suspended solids vary in their seasonal characteristics. By fractionation of the suspended solids, it was possible to separate out the effects of the different processes involved. The smallest size category (0.22 - 1.0 μm) represents inorganic sediment and is most conspicuous after the winter rains, although algal decomposition contributed a little in Sand Canyon Reservoir where algal growth is the greatest of the three reservoirs. The second category (1.0 - 75 μm) relates to planktonic algae which tend to be maximal during the summer and early fall and greater in the two reservoirs receiving reclaimed water than in Santiago Reservoir. Suspended solids in the 75 - 600 μm range do not encompass a single biological category but consist of larger algae, zooplankton and smaller particles of vegetable debris and because of this admixture cannot be fully separated. Suspended solids greater than 600 μm are almost exclusively derived from larger vegetable debris. The amount of this largest size category passing into a reservoir is determined by the type of vegetation present in the watershed (with the greatest quantity coming from grazing areas rather than chaparral) and by the precipitation pattern, not merely of the year in question but of one or two preceding years.

CHAPTER X

RECOMMENDATIONS

The present study represents the first published account of shallow impoundments receiving reclaimed water. Certain recommendations can be made on the basis of the results obtained:

1. There is an obvious need for further studies of bodies of water of this type. Such studies cannot be made on the basis of a single annual cycle because conditions fluctuate greatly as a consequence of the waters of different characteristics entering and irrigation water being withdrawn.
2. Measurements of algal populations alone are of little consequence in investigations of this nature. In order to assess the biological consequences of the storage of reclaimed water, full ecosystem studies are needed, although these are time-consuming and expensive.
3. The use of measurements of algal growth potential have been shown to be an excellent tool for the evaluation of additions of reclaimed water to reservoirs. It would probably be best if studies of algal growth potential were enlarged beyond the scope planned for the present study, so as to include the determination of limiting nutrients.
4. Fractionation of suspended solids gave valuable insight into the management of reservoirs and the technique could be adopted more widely with benefit.
5. As to the storage of reclaimed water, the present study showed that TDS levels were approaching the critical level for use irrigation although heavy metals apparently posed no problem.

CHAPTER XI

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