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ANALYSIS OF SALT WATER INTRUSION IN PUBLIC WATER SUPPLY WELLS: A MANAGEMENT PLAN FOR COCKBURN TOWN, SAN SALVADOR, BAHAMAS.

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ABSTRACT

The Airport Well Field on San Salvador Island, Bahamas, has experienced a ten-fold increase in production since Club Med Columbus Isle opened in 1993. Since then, over-pumping of the eighty-seven wells has caused decrease in quality of production water due to increasing salinity. Using specific conductance measurements as a surrogate for salinity, the water quality at depth in each well in the Airport Well Field was measured at 5-25 centimeter intervals to determine which wells were major sources of saline water. There were 3-7 sampling "events" at each well over a period of three years. Target specific conductance values of 1,500 microSeimens (μS), 2,000 μS, and 2,500 μS (the approximate equivalent of 250, 475, and 600 mg/L chlorides respectively) were compared to measured specific conductance values at various depths in each well to determine whether the ground water was potable. The thickness of the "potable" lens was calculated for each sampling event according to the three specific conductance target values. Management recommendations were made for each well based on these targets. We considered three different well management options: no operational change, raising the elevation of the pump intake to avoid pumping saline or brackish water, and well abandonment. For the target specific conductance value of 1,500 μS, seven wells would require no operational change, fifty wells would need to have the elevation of the pump intake raised, and thirty wells would need to be abandoned. If 2,000 μS was used as a specific conductance target, nineteen wells would require no operational change, fifty-five wells would need to have the pump intake raised, and thirteen wells would be abandoned. Based on the less conservative target specific conductance value of 2,500 μS, nineteen wells would require no operational change, sixty-three wells would need to have the pump intake raised, and five wells would need to be abandoned. While these changes should lead to improved water quality in the short term, it is not clear whether this would be sustainable over the long-term given a continuation of the current high pumping rates.

INTRODUCTION

In 1992, Club Méditerranée ("Club Med") opened a resort (Club Med-Columbus Isle) on San Salvador Island, Bahamas. Unpublished data from the Bahamas Water and Sewer Corporation show that following its opening there was a 10-fold increase in water demand from the island's main production well field which has 87 shallow wells ranging in depth from 3 to 10 meters. This increased demand was accompanied by a decrease in water quality, which was not particularly good to start with. It is likely that the cause of the poor water quality was over pumping and the resulting salt-water intrusion (Erdman, et. al, 1997). The response from well to well, however, was not uniform. Because wells are clustered together with each cluster working off a single pump and because the well clusters are then combined for distribution, it is difficult to reduce the pump rate of a particular well where the water may be "bad." One of the authors (Davis), along with associates (Pociu and Clarke, among others), has been collecting water quality data on these wells for many years. Based on these data, we thought that we might be able to recommend well-field operational changes which would improve the quality of water entering the distribution system. This paper will present our recommendations and discuss the reasoning behind them.

BACKGROUND

San Salvador Island is located approximately 600 kilometers east-southeast of Miami along the eastern flank of the Bahamian Archipelago. A small island of approximately 112 square kilometers, the island spans approximately 14 kilometers north-south and 8 kilometers east-west. The main settlement of Cockburn Town is located on the western side of the island south of the airport, Club Med is located to the west and the well field is immediately adjacent to the south (Figure 1). The geology of San Salvador, similar to the other islands in the Bahamas, consists of carbonate rocks, some of which are very porous and exhibit typical karst features including caves, sinkholes, conduits, and blueholes. Surface elevations on the island range to about 40 meters above sea level, with the maximum elevations occurring where consolidated carbonate dune ridges are found. Low lying areas between the dune ridges are often occupied by shallow hypersaline lakes.

The island's hydrology has been described by others (Klein et. al., 1958, Davis and Johnson, 1989, Erdman, et. al., 1997, Kunze, 1998). In particular, Davis and Johnson (1989) found that while there is a freshwater lens on the island, the hypersaline lakes cause it to be discontinuous. Furthermore seawater is tidally pumped into and out of the island's interior through subsurface conduits and this contaminates many of the freshwater lenses that are present (causing them to become brackish). Given the small size of these lenses, the low hydraulic conductivity of the aquifers, and the low elevation of the ground water table, wells are quite susceptible to salt water intrusion caused by over pumping. Furthermore, as these lenses are frequently thin, it is easy to extend a well below the fresh water/salt water boundary (the halocline) and pump only salt or brackish water.

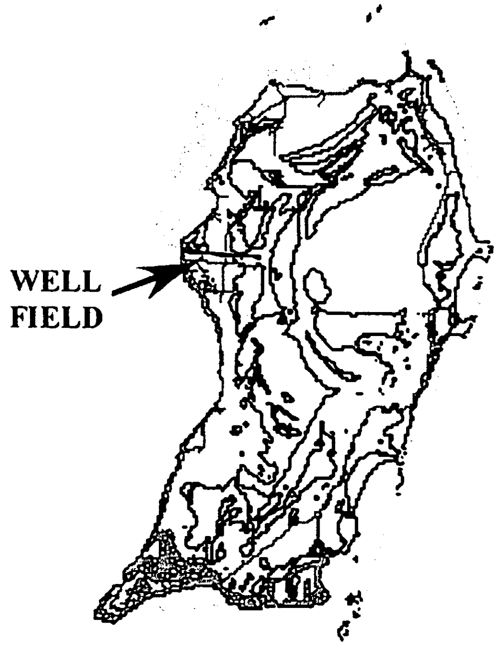

Figure 1. Location of well field on San Salvador.

Description of the Airport Well Field

The water supply well field is located just south of the airport and north of the Cockburn Town settlement. The wells are arranged in lines of 6-13 individual wells (Figure 2). Each line is connected to a centrally located pump house (Figure 3) and the water is pumped into a storage tank (Figure 4) for treatment and distribution.

Originally, there were 11 well lines (Figure 5), three just north of the runway (lines 1-3) and 8 south of it (lines 4-11). In response to the increased water demand posed by nearby Club Med, additional well lines (A-F) were installed in 1999. Also, at this time, the runway was lengthened and the airport improved. In the process all of the well lines adjacent to the runway were destroyed or rendered in accessible (lines 1-3, 9-10), as were the northernmost wells in lines 4-8. As of January 2004, there were 87 water supply wells, connected to 12 production lines being used (4-8, 11, A-D).

In the vicinity of the well field, carbonate bedrock is within 0.5 meters of the surface and the water table is typically 2-4 meters below the surface. Consequently, well construction is relatively simple (Figures 6 and 7). The top (approximately 0.5 meters) of each well is cased with 15-centimeter (cm) (6-inch) diameter polyvinyl chloride (PVC) pipe. The pump intake consists of 5-centimeter (2-inch) diameter PVC pipe that extends to within 10-20 centimeters of the bottom of each well. There are no records listing the depth of the pump intakes, however, based on borehole videography, most intakes are located approximately 15 centimeters from the bottom of each well. Note particularly in Figure 6 that it is possible to locate the intake below the halocline.

Wells are capped with either plywood or PVC covers, through which the 5-centimeter diameter PVC pipe extends. Rubber hoses are then used to connect each PVC intake pipe to a valve that controls whether ground water is drawn from a well ("on" versus "off"). The valve then connects to the pipe that runs to the pump house.

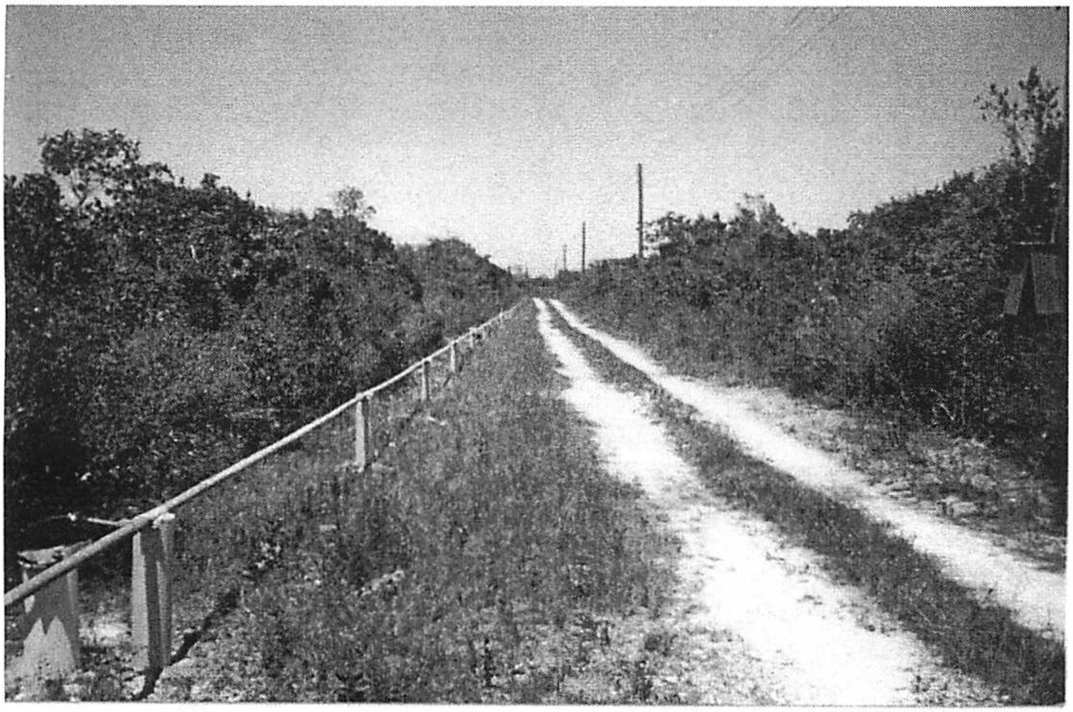

Figure 2: Example of a line of wells. An individual well can be seen in the extreme lower left of the photograph. The wells are connected through a steel pipe to a centrally located pump house.

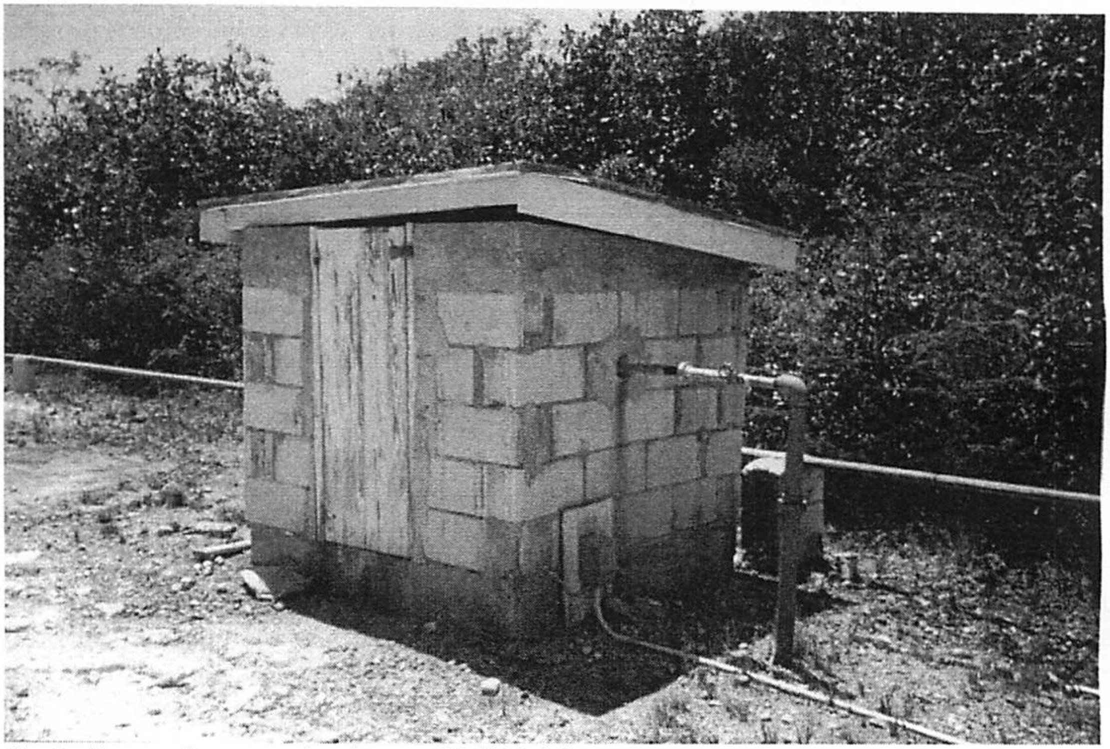

Figure 3: Typical pump house at the Airport Well Field.

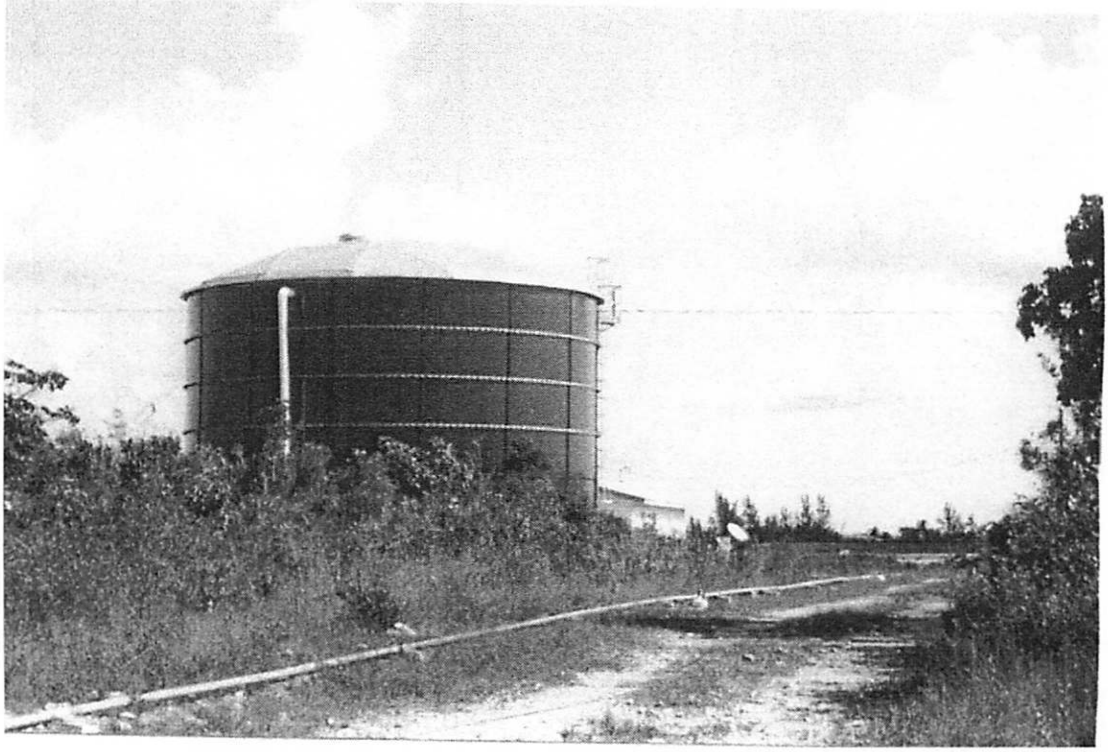

Figure 4: Ground water is pumped from each pump house to this holding tank where water is stored prior to treatment and distribution.

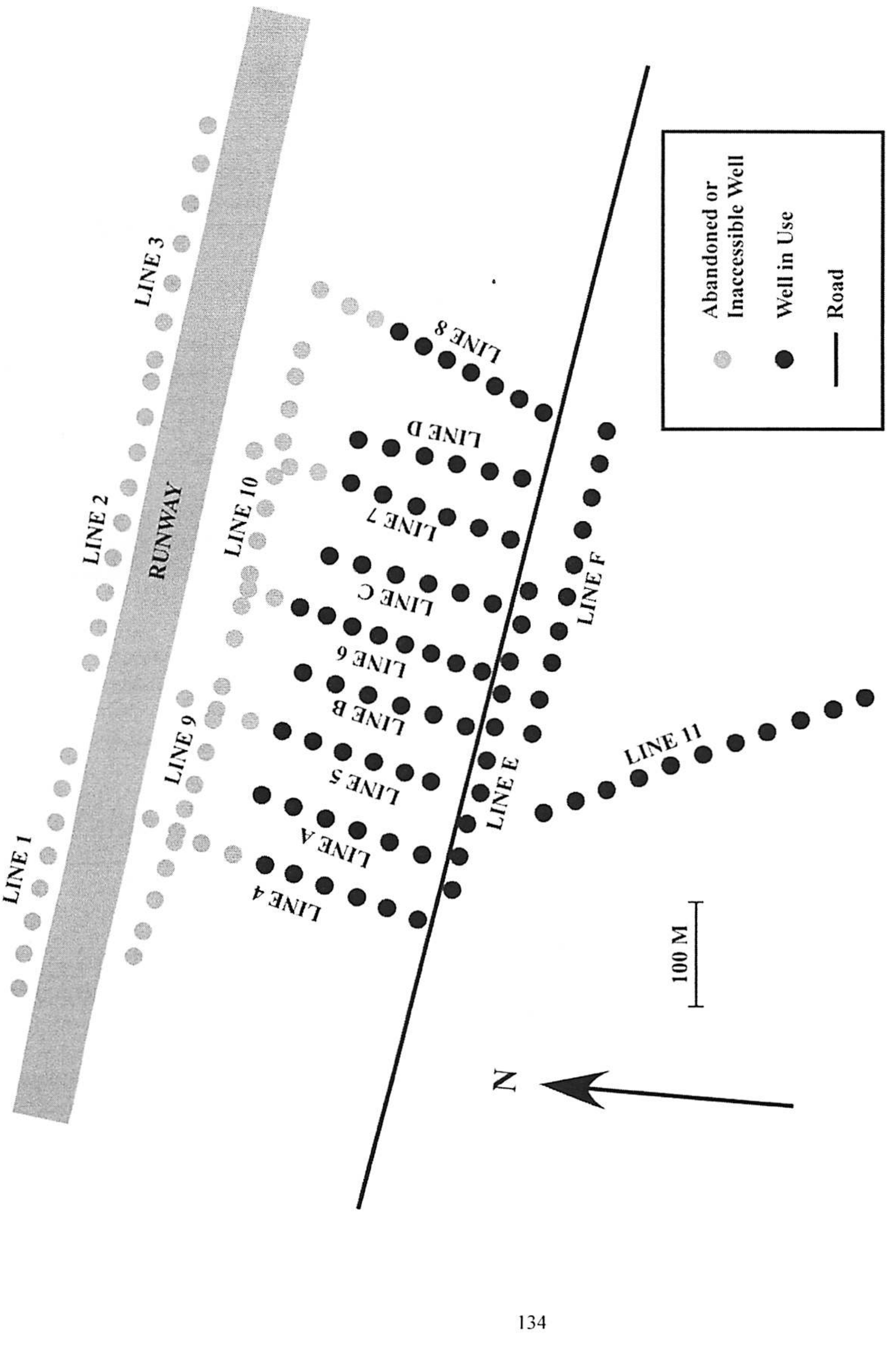

Figure 5: Location of Well Lines, Cockburn Town Well Field, San Salvador, Bahamas

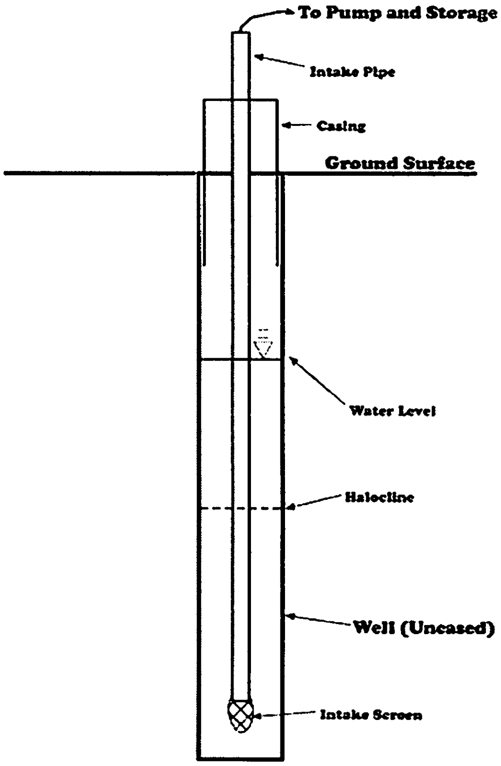

Figure 6: Well construction details.

METHODS

In order to develop a strategy for improving the quality of water distributed from the well field, it was necessary to determine the water quality and halocline location for each individual well. A common method for doing this is to use a conductivity meter to measure the water's electrical conductivity at discrete intervals in the water column within each well. Conductivity is a measure of the ion concentration in a solution and, in this situation, can be used as a surrogate for water quality. Saline water, with a greater concentration of ions in solution than fresh water, will display greater conductivity. One of the authors (Davis) has been carrying out conductivity measurements in the well field since 1998. Additional measurements were made in connection with this study. Unpublished data show conductivity values ranging from approximately 250 microSiemens (µS) for fresh-water to more than 100,000 µS for saline water. This corresponds to salinities (total dissolved solids) in the range of 125-50,000 mg/L .

The measurements were taken using a YSI model 61 model meter which measures temperature, pH, conductivity, specific conductivity (adjusted for temperature) and which provides an estimate of salinity. The meter comes with a probe attached to a 50-foot long cable. First, the depth to water (from top of casing) is measured using a water level indicator. This will vary as the water table elevations vary both with climatic conditions and with tides. Then the conductivity probe is lowered down the well and readings are taken at regular intervals (Figure 8). These intervals vary from 25 centimeters above the halocline to 5 centimeters near it and below it. In most wells there is a sharp halocline (Figure 9) and by subtracting the depth to this boundary from the depth to the water table, you can obtain the thickness of the fresh water lens in the well.

In order to determine which production wells were producing fresh, brackish, or saline water, we examined all the water quality data between 1999 and 2003 to determine the thickness of the "potable lens" in each well. Data collection occurred during January 1999, January 2000, January 2001, April 2001, December 2001-January 2002, May 2002, and April 2003. Not all wells were examined during each sampling period due to well cap accessibility, obstructions within wells, and time constraints. Data for each well was examined for trends and variance.

Using specific conductance target values of 1,500 µS, 2,000 µS, and 2,500 µS for determining potablity, data were analyzed to determine which wells exceeded these values. These target specific conductance values were selected based on aesthetic qualities (taste) to provide a range of management options. Salinity is generally not detected by taste in water with specific conductance values less than 2,000 µS. Next, the depth at which groundwater exceeded target specific conductance value was identified for each well. Using this information, the thickness of the "potable lens" was calculated. For those wells in which measured specific conductance values did not exceed the threshold comparison value, the thickness of the potable lens was calcu-

Figure 7: Typical well head at the Airport Well Field.

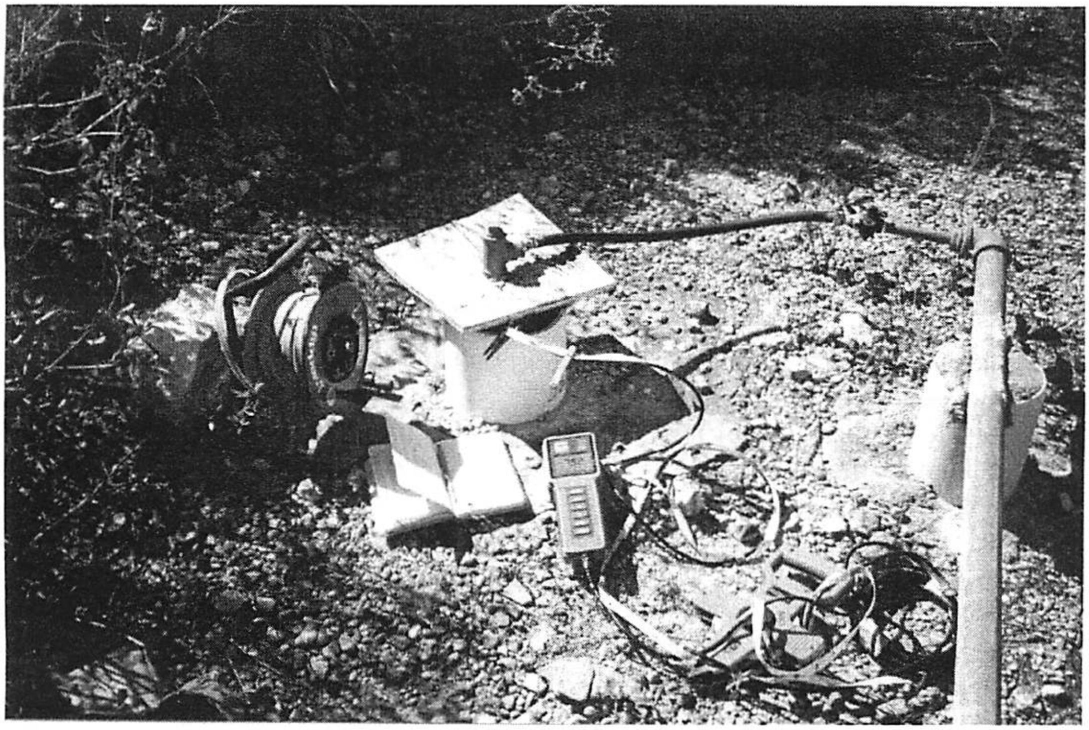

Figure 8: Well measuring set-up. The water level indicator is to the left of the well and the conductivity meter (with tape measure attached) is in the foreground. The probe is down the well.

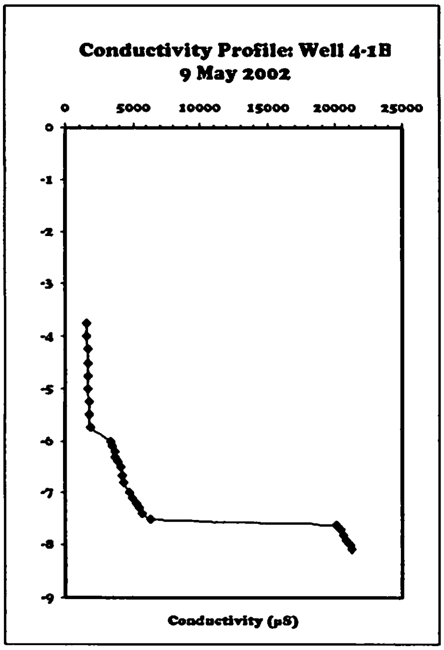

Figure 9: Typical conductivity profile. Note the sharp halocline at about 7.8 meters. At this point conductivity increases almost three fold over a 5 centimeter interval.

lated simply as the difference between the depth to the bottom of the well and the depth to the water. We used the potable lens thickness to assign each well to one of three possible management options: no operational change, raise the elevation of the pump intake, or well abandonment. The decision criteria were based on practical considerations. If specific conductance for a well at all sampling events were less than the target value, then we recommended no operational change. If specific conductance values exceeded the target value in all sampling events and the thickness of the potable lens was less than 2 meters we recommended abandoning the well as a water supply source. Finally, we recommended raising the water intake (Figure 10) if specific conductance values exceeded the target value in some, but not all, sampling events for a well, if the potable lens was greater than 2 meters in thickness, and if the pump intake could be at least 1 meter below the water table and 1 meter above the depth at which specific conductance reached the target value.

The recommendations were not always clear-cut. In some cases where the target value was exceeded in all sampling events, but the potable lens thickness was significant, then we recommended raising the pump intake. Where the water quality in the well was erratic over the several sampling periods, we recommended raising the pump intake first to see if that adjustment improved the water quality. If it did not, then the well would have to be abandoned.

ANALYSIS AND RECOMMENDATIONS

Using the criteria described in the preceding section, for each well, recommendations were made to raise the pump intake, abandon the well, or do nothing. A summary of the recommendations is shown in Table 1. If the more conservative specific conductance standard of 1,500 µS is used to determine potablity, the greatest number of wells would need to be abandoned (30) and the fewest number of wells would require no change (7). In comparison, using the most liberal potablity threshold of 2,500 µS would require the abandonment of only 5 wells and no operational change to 19 wells. In all cases, raising elevation of the pump intake is recommended for the majority of wells. Figures 11, 12, and 13 show general recommendations at each target value for the wells. Specific recommendations have been provided to the Bahamas Water and Sewer Corporation.

A review of Figures 11-13 reveals some spatial patterns between well location and recommendations for well abandonment. In the northern half of the well field, there appears to be an east-west trending line of wells that exhibit poor water quality. This trend is most apparent in Figures 11 and 12, which depict management recommendations based on threshold specific conductance values of 1,500 µS and 2,000 µS. Review of the figures also shows that ground

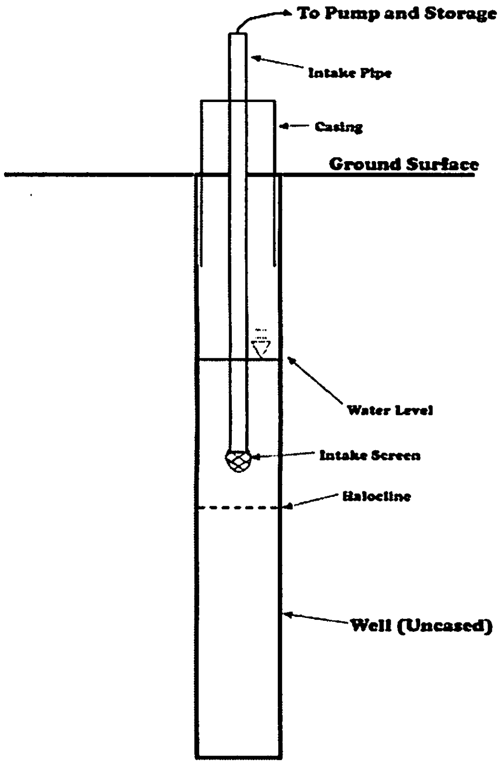

Figure 10: Well with intake screen raised above the halocline.

Well Recommendation	Threshold Specific Conductance Value		
	1,500 µS	2,000 µS	2,500 µS
No change	7	19	19
Raise pump intake	50	55	63
Abandon well	30	13	5

Table 1: Summary of recommendations for different target conductivities.

water quality is generally good (i.e., no operational change needed) for several wells in lines E and F, with the exception of two wells for which abandonment is recommended. This, however, may be because these wells lines were little used during the sampling period.

CONCLUSIONS

Analysis of water quality data for the 87 wells at the Airport Well Field indicates that many wells should either be abandoned or have the pump intakes raised to avoid pumping saline or brackish water into the Cockburn Town water supply system. The karst geology of the island makes it difficult to predict where saline conditions may be encountered, but by maintaining an adequate freshwater lens, the amount of saltwater intrusion can be minimized. The management of fragile groundwater resources is critical on San Salvador if the island's population continues to grow. By responsibly maintaining the current Airport Well Field, this potable water resource can be preserved and use can continue. However, over pumping of the well field that results in upconing of saline water can degrade the quality of the water, rendering it unusable as a drinking water supply. The management recommendations presented here can be used as a first step towards improving the drinking water quality of the water pumped from the shallow aquifer. The local government and the Bahamas Water and Sewer Corporation should work together on long-term land use planning and water supply issues to ensure that future development can be sustained by the island's limited fresh water resources.

Finally, in addition to the well management recommendations presented in this report, the following suggestions to optimize the water quality and quantity of the Airport Well Field should be considered for the long-term management of the potable water supply.

1. Abandon additional wells if raising the pump intake does not result in a decrease in specific conductance levels to desired potable levels.

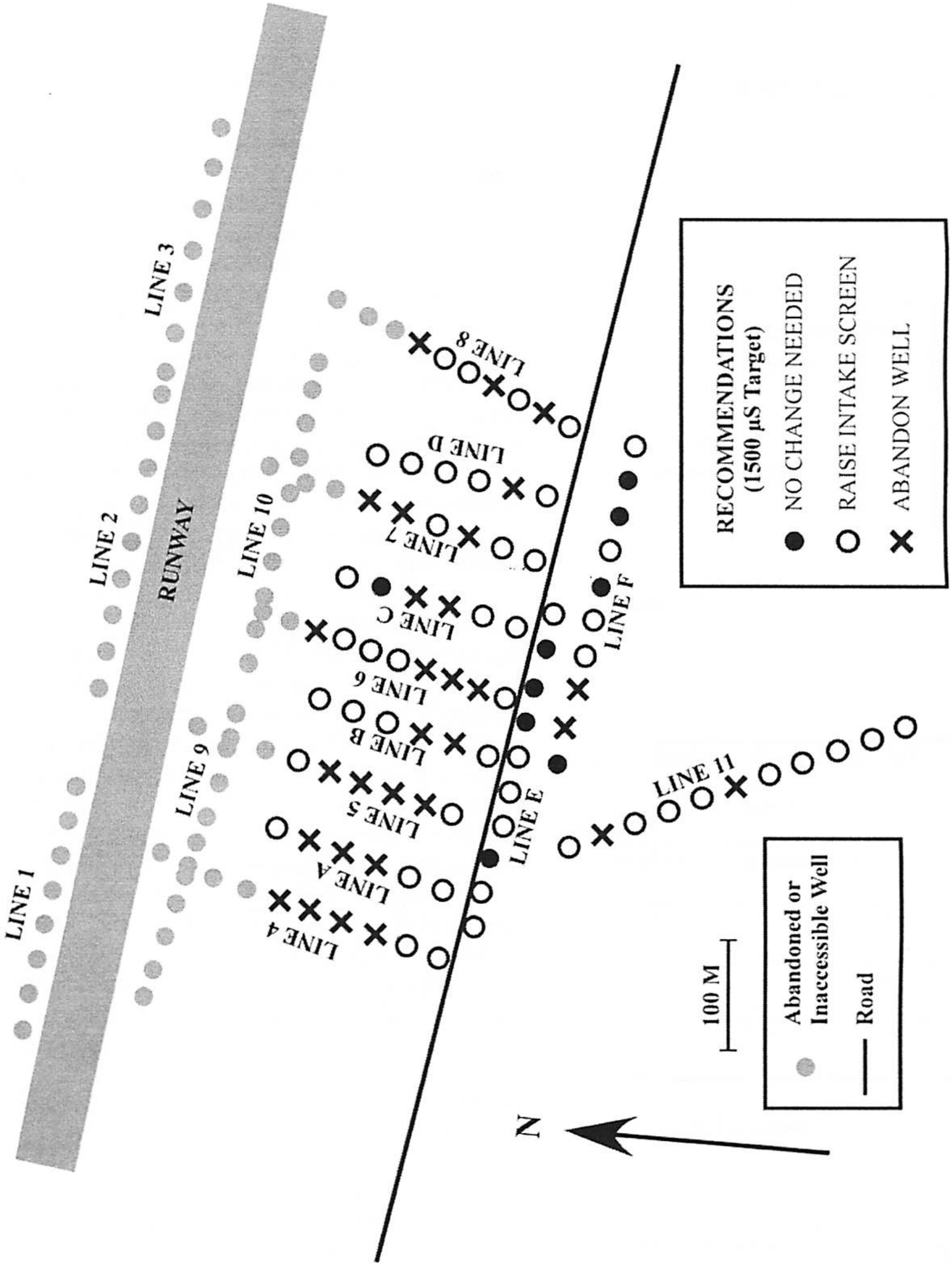

Figure 11: Recommended well management actions for 1500 μS target conductivity.

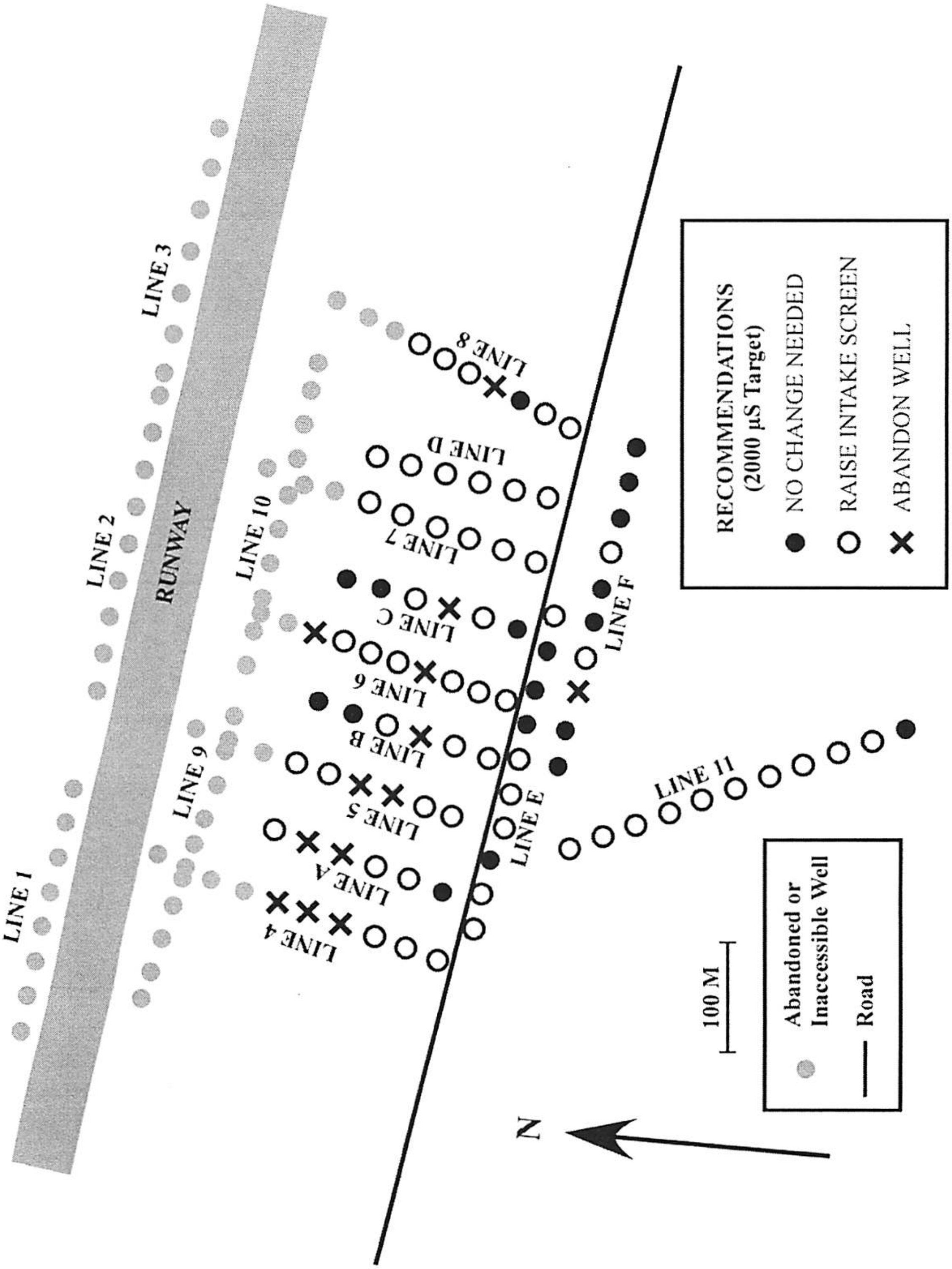

Figure 12: Recommended well management actions for 2000 µS target conductivity.

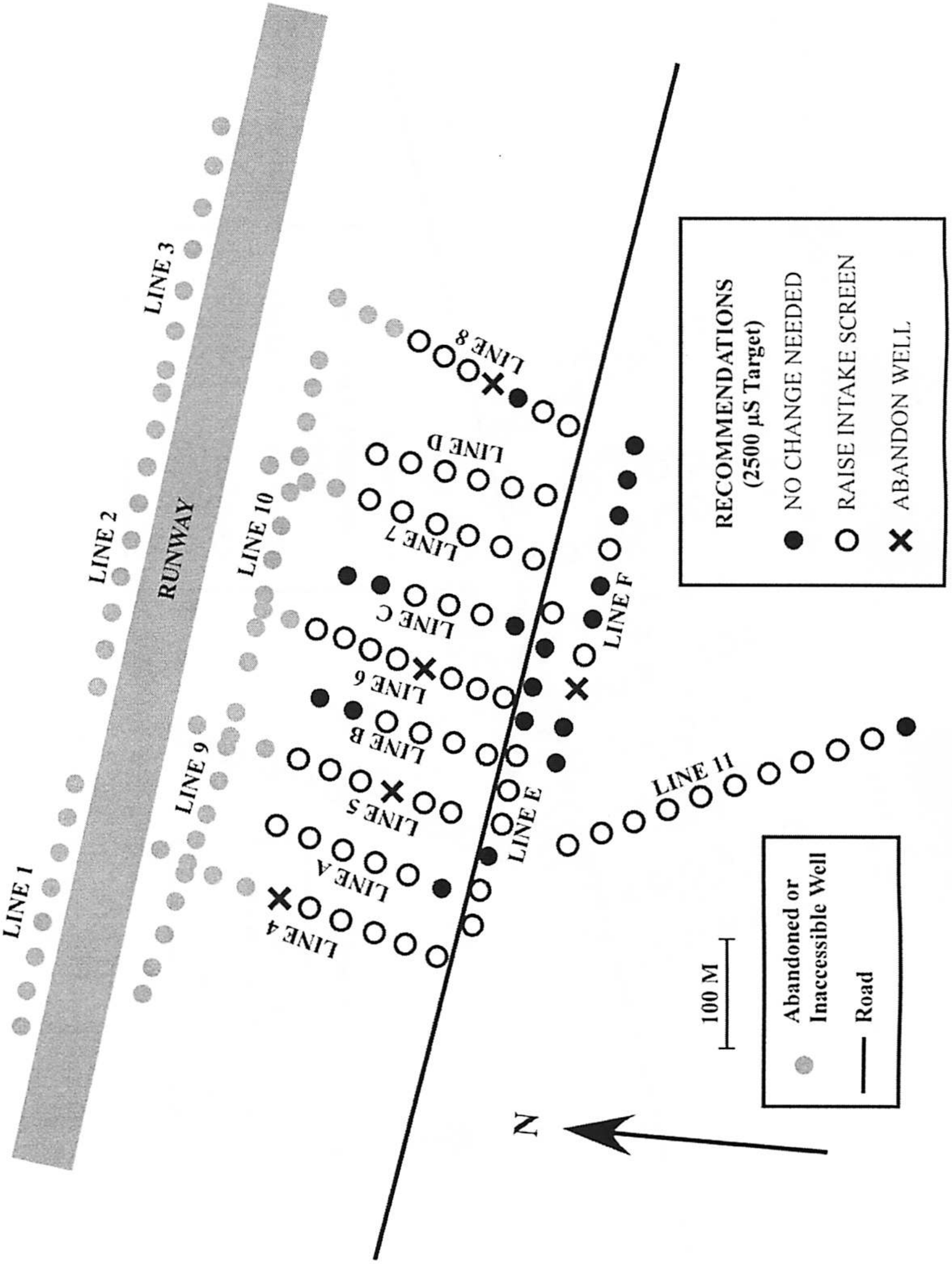

Figure 13: Recommended well management actions for 2500 µS target conductivity.

2. Adjust the pump rates of individual wells. This may be important for wells that exhibit a sharp halocline at depth. Control of the pumping rate of individual wells may prevent drawing saline water into the water supply wells while still effectively maintaining the well as a resource.
3. Note seasonal variations in wells. It may be possible to withdraw more potable groundwater during the wet season or shortly thereafter and then store the water for use during the dry season.
4. Install additional potable water supply wells in areas outside of the current well field to avoid permanent water quality degradation of the Airport Well Field aquifer from over-pumping.

Develop surface water catchments to collect rainwater during the wet season. Precipitation gathered in catchments can be contained in a storage tank for use during the dry season, or blended with groundwater from the well field to improve water quality standards.

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