Dependence of groundwater recharge in the Niles Cone Groundwater Basin on climate variability and inter-basin water transfers

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2012-08-31

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Abstract

The Alameda County Water District (ACWD) supplies water to the cities of Fremont, Newark and Union City. Approximately 40% of this supply requirement is met using water pumped from the Niles Cone Groundwater Basin. Since 1920s, the ACWD has managed recharge operations at Niles Cone and today the water for recharge is obtained from the State Water Project, run off from Alameda Creek Watershed or from direct rain that falls on the Niles Cone region. This paper examines the dependence of recharge operations on precipitation in the Alameda Creek Watershed. Using data from the past 20 years, the paper demonstrates the dependence of Niles Cone Basin on the outlier wet year of 1997-98 to maintain a net positive water balance with respect to levels in 1988-89. Further research using longer time series data of groundwater recharge should be able to provide more evidence of the extent of this dependence on heavy rainfall years to maintain net positive groundwater levels. Such research will be significant in ensuring urban resilience in the context of climate change scenarios we seem to be facing.

1 INTRODUCTION

1.1Global Context

Across the world, groundwater plays a significant role in meeting human water needs. According to estimates available from the United Nations Environment Programme (UNEP), approximately 51% of drinking water supply in the US is obtained from groundwater.[1]

Expanded groundwater use in a global context can be seen as a second step in the continued and accelerated quest for water for human development. Surface water is usually accessed, appropriated and allocated first, as this resource is more visible and readily available; most human settlements occurred near rivers and streams which ensured easy access to water. As surface water resources are being exhausted and strained in terms of quality and the options to dam them have diminished, groundwater has become the second-generation resource to be captured and appropriated. [2]

But over-extraction of groundwater can lead to multiple environmental issues like reduced spring and stream flows, aquifer pollution and land subsidence, documented in cities like Beijing and Shanghai. [3]

Agriculture and cities are often in competition for these scarce resources even as most countries are in the process of over-pumping their aquifers. Many of the world's largest cities, such as Los Angeles, Cairo, and New Delhi, can increase their water consumption only by taking it from agriculture. [4]

The city of Chennai in southern India is another example of this trend, where farmers sell ground water to the city, since it provides more returns than selling crops which are grown with the same water. [5]

1.2 Groundwater in California

In California, groundwater supplies about 30 percent of overall dedicated water supplies in average precipitation years while in dry years, this increases statewide to about 40 percent. This is because when surface water supplies are restricted, both local water agencies and farmers increase groundwater pumping to meet water supply needs. At least 43 percent of Californians obtain at least a portion of their drinking water annually from groundwater sources. During years when surface water deliveries are not available and rainfall is scarce, groundwater may provide up to 100 percent of irrigation water for certain areas. [6]

California is not only the single largest user of groundwater in the US, but the estimated 14.5million acre-feet of water extracted in California in 1995 represents nearly 20% of all groundwater extracted in the US. [7]. In this context, conjunctive ground and surface water management is particularly applicable in California. The term conjunctive water management refers to the active management of aquifer systems as an underground reservoir. During wet years or the rainy season, the surplus surface water is usually diverted to percolation ponds such that aquifers are recharged. During dry years or the summer season, this water is then extracted to supplement other available sources.[8]

1.3 The Niles Cone Groundwater Basin.

The Niles Cone Groundwater Basin in the San Francisco Bay area is a good example of conjunctive management of an aquifer in an effort to meet urban water requirements. As delineated by the Department of Water Resources (DWR), the Niles Cone Basin refers to the alluvial fan depositional zone formed where Alameda Creek exits Niles Canyon as Alameda Creek flows to the San Francisco Bay as shown in Figure 1.

The Niles Cone exists almost exclusively within the boundaries of the (Alameda County Water District (ACWD) (Figure 2). However, given the structure of the aquifer, certain layers of water-bearing deposits like the Newark and Centerville-Fremont aquifers do extend substantially beyond the boundaries of the ACWD as can be seen in Figure 3. In addition there is evidence of hydrologic connectivity between the Deep Aquifer and the South East Bay Plain Groundwater Basin to the North. [9]

Recharge of the Niles Cone Groundwater Basin is achieved by diverting water from the Alameda Creek flood control channel into the Quarry Lakes. These lakes were former gravel quarries which have been repurposed to function as percolation tanks. Along with direct rainfall onto the basin, this recharge helps to ensure that approximately 40% of the water required to serve the clients of ACWD is met by water pumped from Niles Cone without lowering the groundwater level below sea level.

Sixteen wells are used to extract water from the groundwater basin. Together, these wells are capable of producing up to 47.5 million gallons of water per day. This water is blended with water from the Hetch Hetchy pipeline before being delivered to customers. [10]

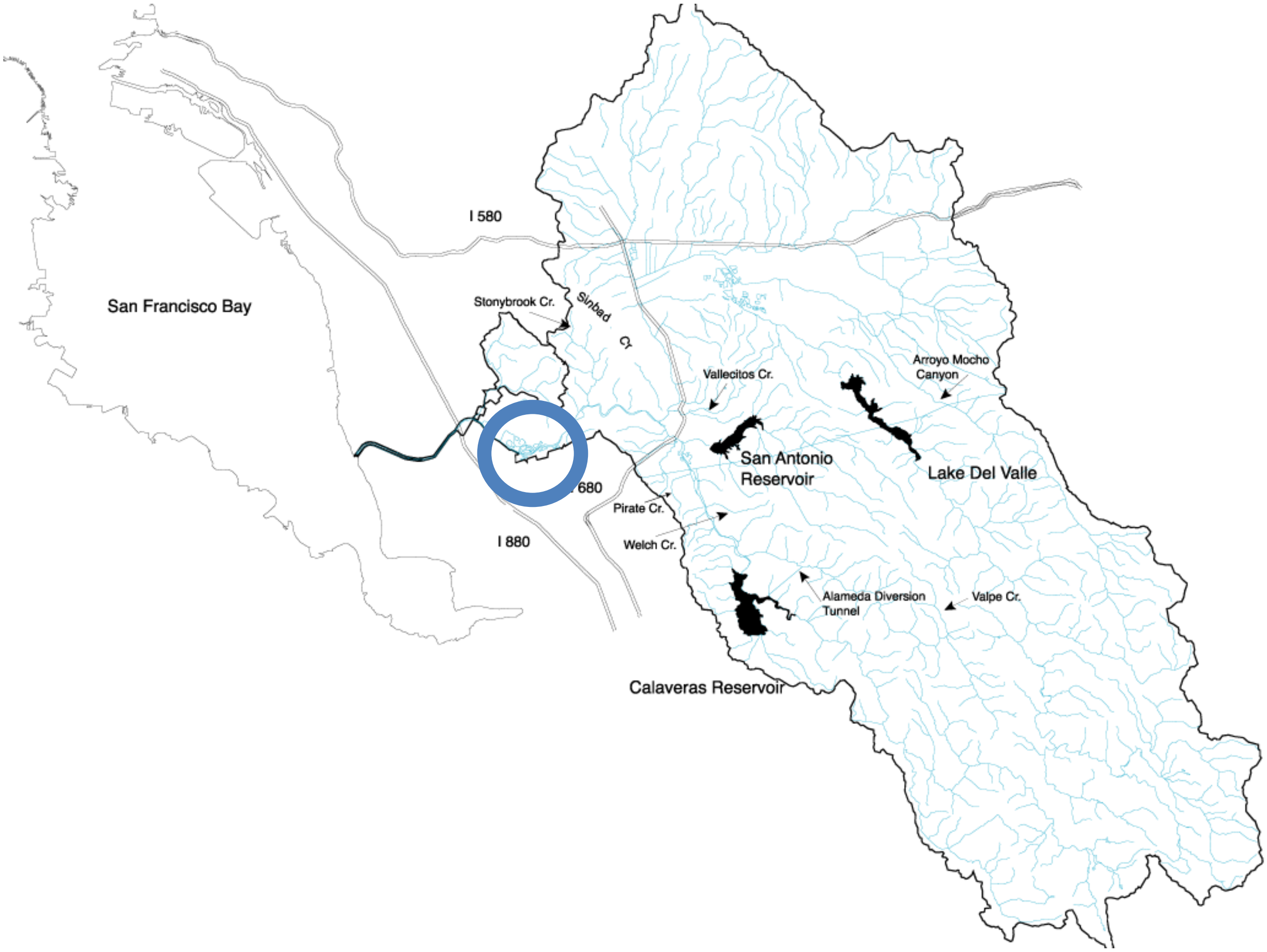


Figure 1: Alameda creek watershed
Location of Quarry Lakes recharge facility indicated with blue circle

Source: http://www.cemar.org/alamedacreek/acmaps.html

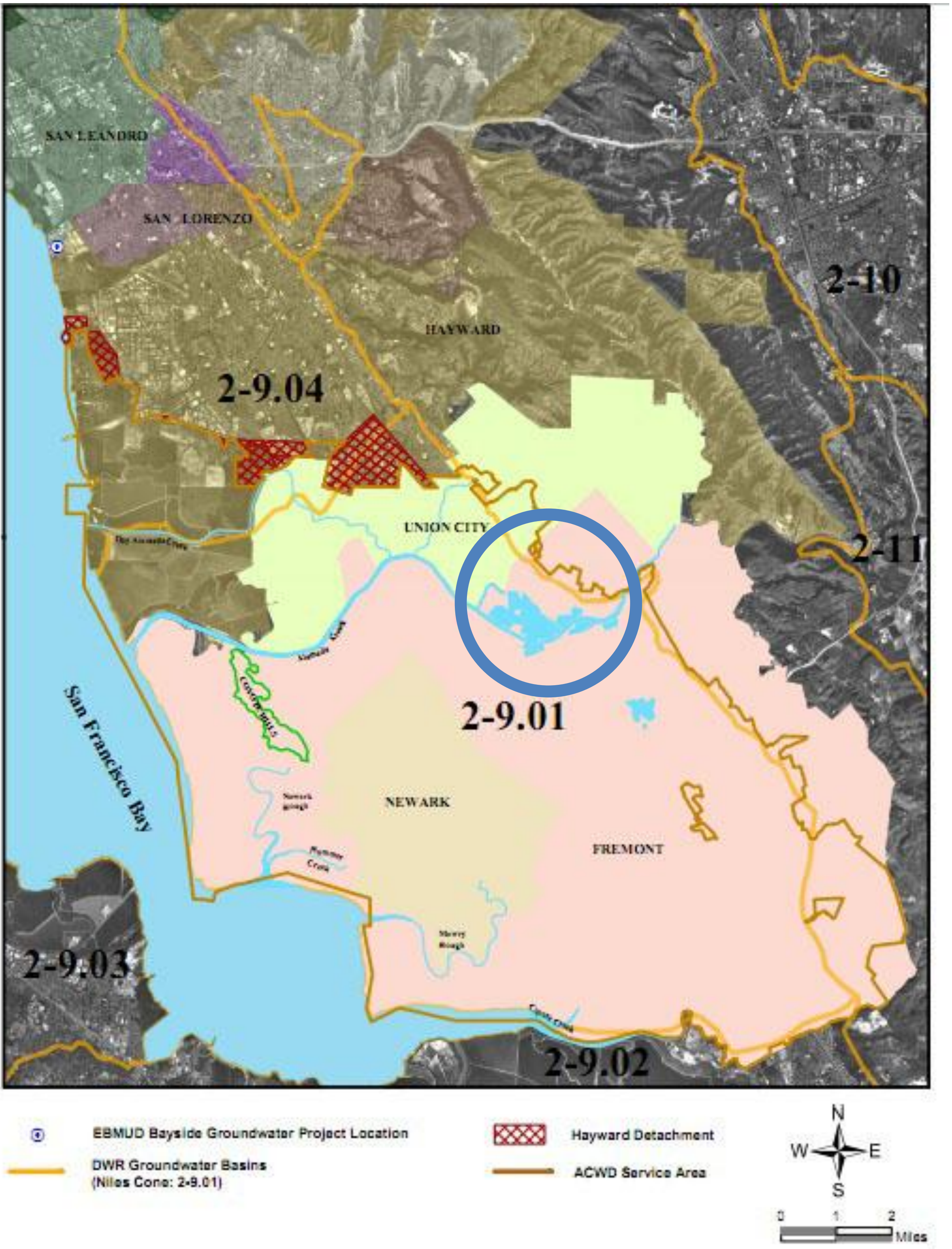
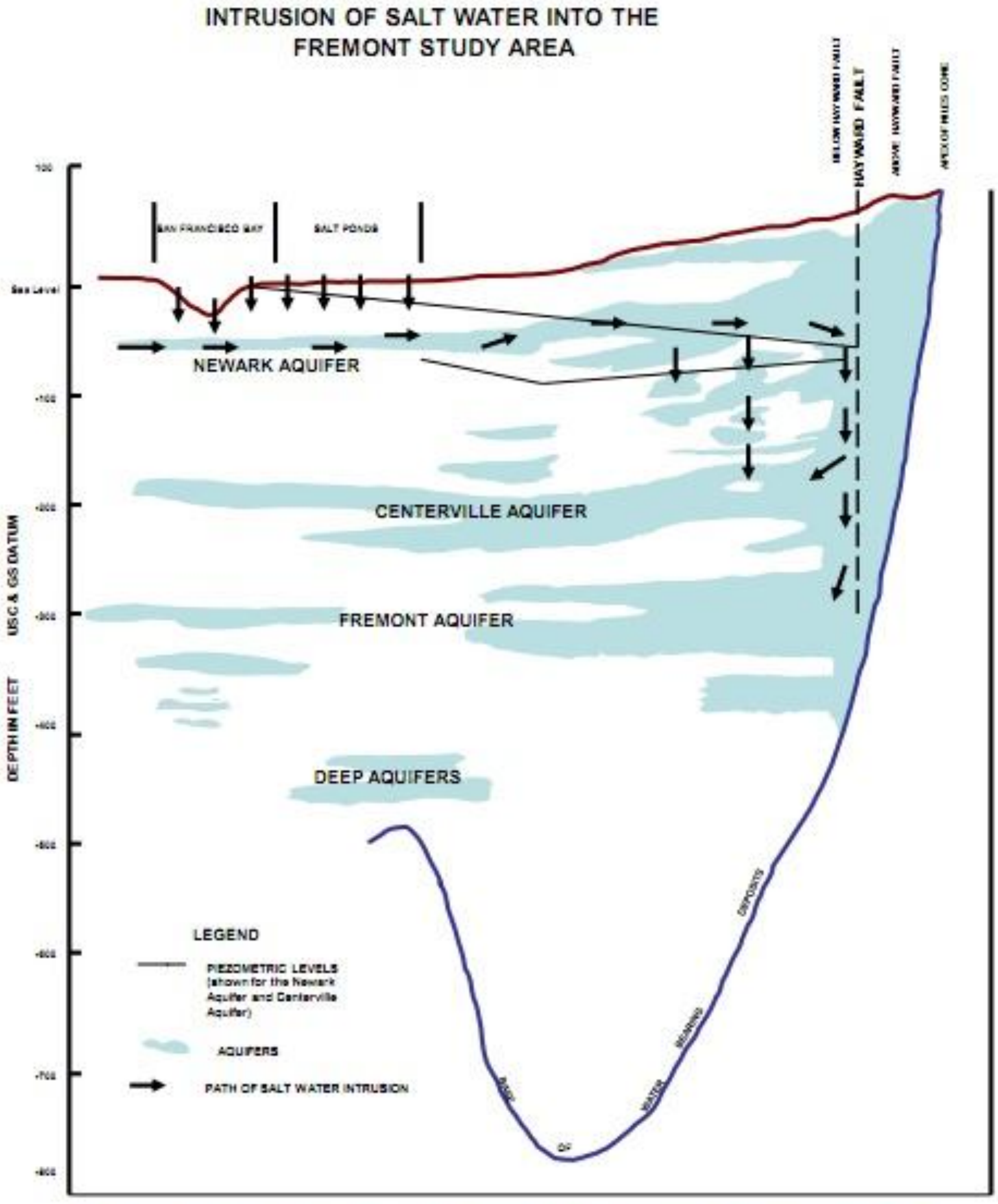


Figure 2: Niles Cone Groundwater Basin

Location of Quarry Lakes recharge facility indicated with blue circle

Source: Survey report on groundwater conditions February 2011, ACWD.



Source: State of California Dept. of Water Resources. 1968. Bulletin No. 118-1 *Evaluation of Groundwater Resources, South Bay, Volume 1: Fremont Study Area*. August, 1968. Sacramento, Calif.

Figure 3: Aquifer structure of Niles Cone Groundwater Basin

Source: Survey report on groundwater conditions February 2011, ACWD.

Overdraft of the aquifer from the 1920s to the 1960s without adequate recharge caused sea-water intrusion into the Niles Cone Groundwater Basin. The Aquifer Reclamation Program was started in 1973 with the aim of improving water quality in certain areas of the Niles Cone Basin. This involves extracting brackish water from the Basin and allowing recharged fresh water to take its place, such that over time the effects of salt-water intrusion can be negated. [11]

The continued protection and enhancement of the Niles Cone Groundwater Basin is vital to ACWD's ability to continue to meet the water supply needs of the people it serves. Consequently, the basin has been the object of vigorous conservation activities on the part of the District. These activities have included an extensive monitoring program to determine the location and movement of saltwater that has intruded into a portion of the groundwater basin. [12]

1.4 Sources of water for recharge and vulnerability

The water used for recharge comes from precipitation within the Alameda creek watershed and the Niles Cone Basin area and inter-basin transfer from the State Water Project via the South Bay Aqueduct. The South Bay Aqueduct receives the water from Bethany Reservoir which in turn receives the water from the Sacramento-San Joaquin Delta.

1.4.1 Alameda Creek Watershed

The Alameda Creek watershed is an area of approximately 633 square miles which is populated by more than 200,000 people living in five cities - Dublin, parts of Danville and San Ramon, Livermore, Pleasanton - and thousands more living in unincorporated areas.

Average rainfall in the watershed is 20 inches per year and the runoff is collected in three reservoirs. The Calaveras and San Antonio Reservoirs collect runoff from the southern regions, which are part of San Francisco's water system while runoff from much of the southeast portion is collected in Del Valle Reservoir, some of which is diverted to ACWD via the South Bay Aqueduct. Runoff from the northern region flows to tributaries of Alameda Creek, where it is carried to ACWD facilities and used for groundwater recharge. [13]

1.4.2 State Water Project

Planned, designed, constructed, operated and maintained by the California Department of Water Resources (DWR), the State Water Project (SWP) is the largest state-built, multipurpose water project in the United States. The SWP, spanning more than 600 miles from Northern California to Southern California, includes 32 storage facilities, 17 pumping plants, 3 pumping-generating plants, 5 hydroelectric power plants, and approximately 660 miles of canals, pipelines, and tunnels. [14]

The State Water Project releases water into Alameda Creek near the town of Sunol and this water along with the runoff from the Alameda Creek Watershed flows down to the Alameda Creek Flood Control Channel where it is captured behind three large inflatable dams. These dams are used to divert water to the Quarry Lakes percolation ponds during the high flow season. [15]

1.4.3 Vulnerability

Allocating water from the Delta has been the subject of conflicts and disputes among stakeholders such as farmers, urban water contractors, and environmentalists for years. The Delta now supplies water to 22 million people and millions of acres of farmland in California. The combined annual amount of water taken by the Central Valley Project and the State Water Project ranges between 20% and 70% of the total annual inflow in the Bay-Delta region. [16]

The conflict between Delta water exports and environmental protection reached a peak in the late 1980s and early 1990s. The 1987-1992 drought – the second worst drought in California history – resulted in reduced water deliveries to farms and cities up and down the state. It also exacerbated conditions for fish and wildlife. [17]

While competition from agricultural and environmental requirements sets limits to the amount of water that would be available from the Delta, the supply of water from Alameda Creek Watershed is dependent on availability of direct precipitation. According to studies by the California Climate Change center, a warm-dry scenario of climate change could cause a 27% reduction in precipitation across all groundwater basins. [18]

In this context it is important to investigate the vulnerability of this system to climate change and intra basin water transfer.

California depends substantially on groundwater for both urban and agricultural use. The Niles Cone Basin is an example of conjunctive water management, with groundwater for urban use and recharge during high flow season. Below, I explore the dependence on the various sources of recharge water and how this may be affected by climate variability.

2.0 RESEARCH METHODS

A field visit was undertaken to the Alameda Creek Flood Control Channel and the water diversion with the hydrology class on February 5, 2011. I was able to see the inflatable dams and understand the process of water diversion and recharge from the ACWD representatives.

I obtained raw time-series data about water recharge into the Niles Cone Basin and water supply by the ACWD for the water years 1989-90 to 2008-2009. This was in the form of data graphic / flow charts which form the annual ‘Water Supply/Demand Inventory’. Figure 4 shows a sample data graphic. I converted these data into an Excel sheet database and calculated various useful metrics.

The significant metrics computed and their definitions are given in Table 1 below. I conducted initial statistical explorations and outlier identification using line graphs generated based on these metrics.

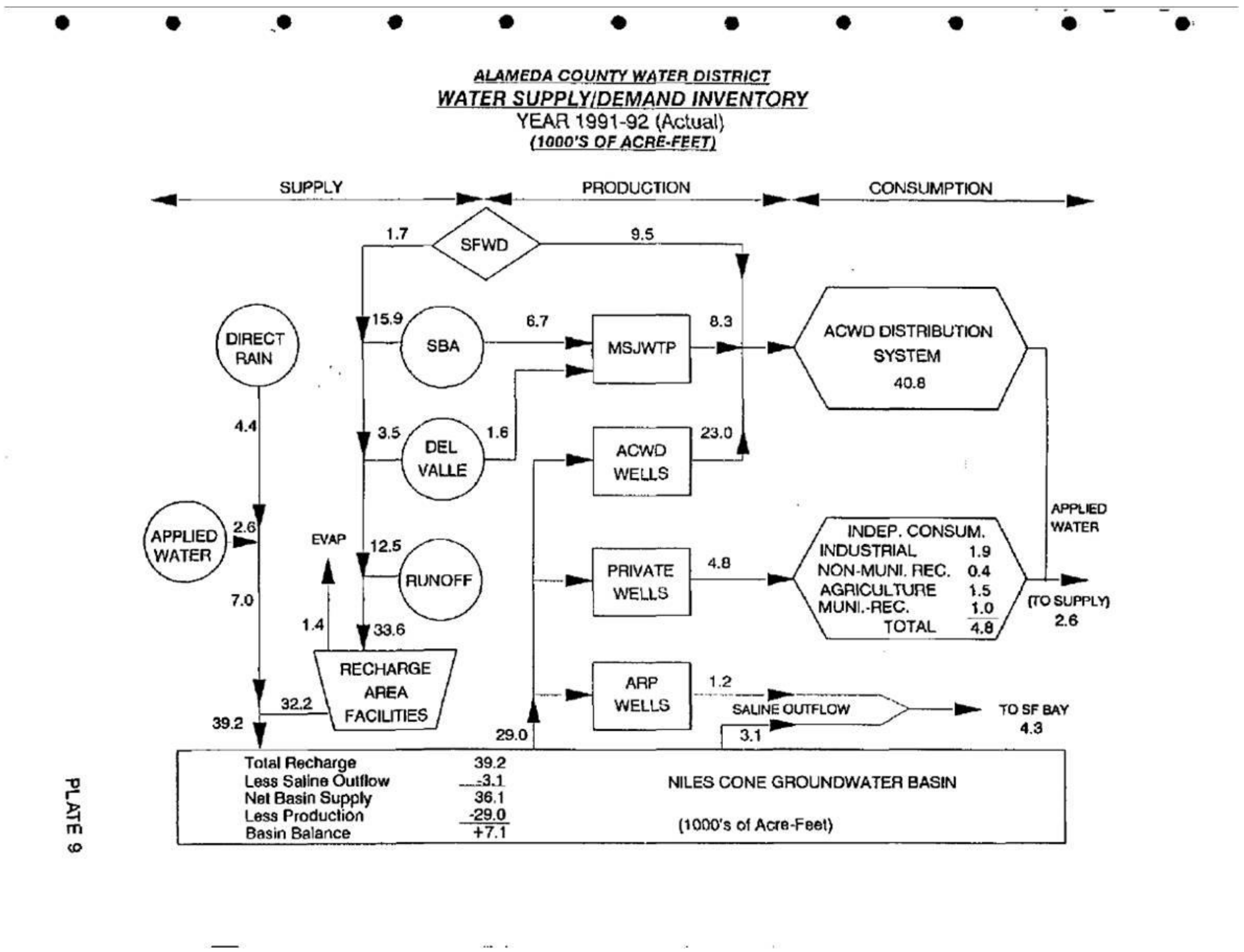


Figure 4: Sample data graphic showing water supply/demand inventory obtained from ACWD
Source: Alameda County Water District

Metric	Definition
SBA	Water received from the Delta via the South Bay Aqueduct
Annual Balance	Annual water balance in the Niles Cone Basin
Net Balance	Cumulative water balance in the Niles Cone Basin (relative to 1989 levels)
All Wells	Total groundwater extraction from ACWD and private wells combined
Direct Rain	Recharge water received as a result of direct rainfall onto the Niles Cone Basin
Runoff	Recharge water diverted from the Alameda Creek Flood Control Channel

Table 1: Legend for the metrics used in graphs

Historical rainfall data from 1896 to 2010 were obtained from the California Climate Tracker website maintained by the Western Regional Climate Center (WRCC) (http://www.wrcc.dri.edu/monitor/cal-mon/index.html) to understand frequency and scale of rainfall within this climate region. According to the climate region delineation used by the WRCC, the Niles Cone Basin and the Alameda Creek Watershed falls within the Central Coast region.

I used the ACWD time series data and the historical rainfall data to develop further scenarios regarding net water balance in the aquifer with respect to 1989 levels. The tested scenarios were:

1. Absence of water supply from the Delta via the South Bay Aqueduct.
2. Removal of the outlier rainfall year.
3. Substitution of outlier year rainfall with median year rainfall from historical rainfall data.

3.0 RESULTS

Based on initial exploratory statistical analysis, relative to 1989 water levels, over the next 20 years the Niles Cone Basin appears to be net water positive (Figure 5). Total supply from the Delta via the South Bay Aqueduct (SBA) and total extraction from ACWD and other private wells closely track each other. During the period of study both the supply from SBA and production from wells peak around 90-91 which was a period of drought in California.

Availability of recharge water rises sharply during the year 97-98, which was a year of very high rainfall in California. From 115 years of historical rainfall data for the region, it is clear that 97-98 is definitely an outlier year (Figure 6). The mean rainfall for the 115 years is 25.23” and standard deviation is 8.94” while in the year 97-98, 51.02” was recorded. This shows that the year recorded rainfall for the year 97-98 is more than 2.88 standard deviations away from the mean, which makes it a clear outlier.

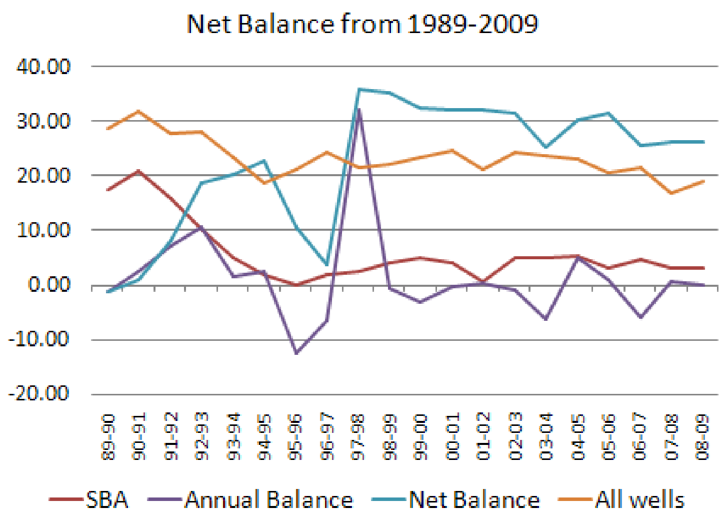
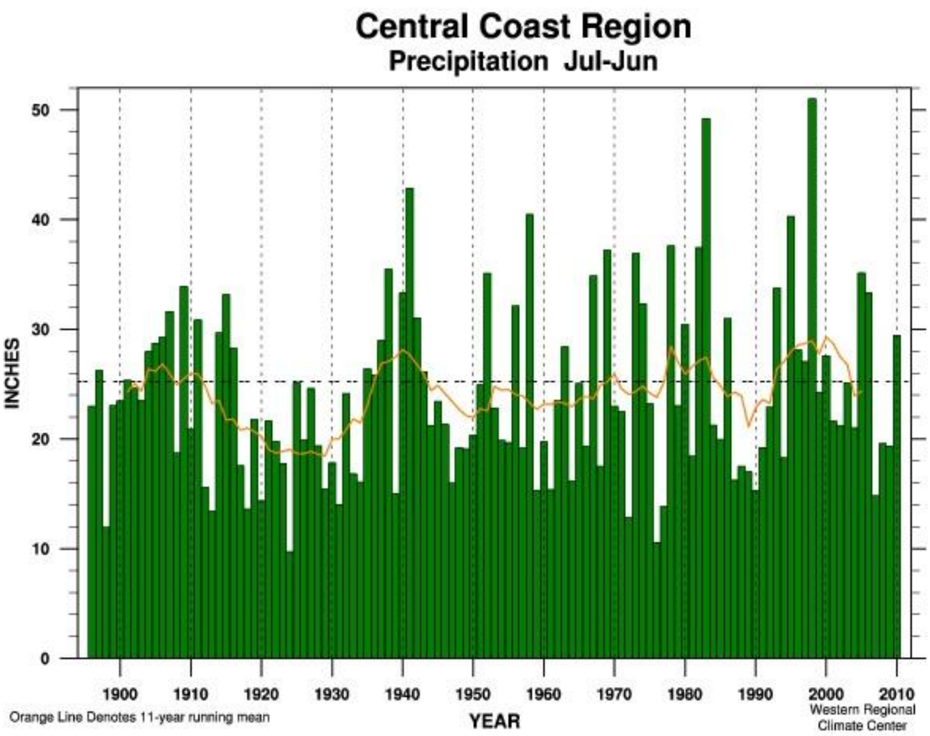


Figure 5: Overall trends for period of study



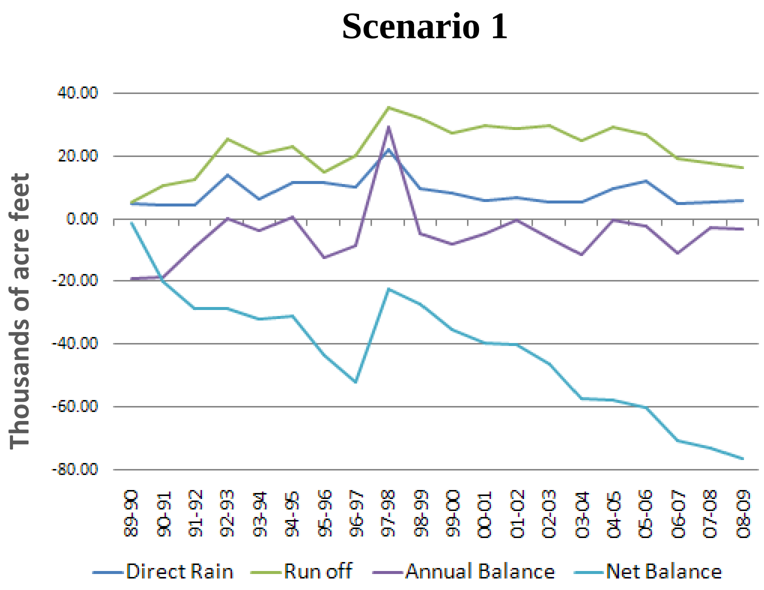
Linear Trend 1895-present	+ 3.22 ± 4.42 in.	(+ 12 ± 17%) per 100 yr		
Linear Trend 1949-present	+ 3.79 ± 12.89 in.	(+ 15 ± 51%) per 100 yr		
Linear Trend 1975-present	+ 4.53 ± 33.19 in.	(+ 17 ± 131%) per 100 yr		
Wettest Year	51.02 in. (202%)	in 1998	MEAN	25.23 in.
Driest Year	9.72 in. (38%)	in 1924	STDEV	8.94 in.
Jul-Jun 2010	29.44 in. (116%)		RANK	89 of 115

Figure 6: Historical rainfall data for the Central Coast from California climate tracker
Source: http://www.wrcc.dri.edu/monitor/cal-mon/frames_version.html

Scenario 1. Subtracting the supply of recharge water from the Delta via the South Bay Aqueduct from the Alameda water balance illustrates the importance of this supply on maintaining a net gain in recharge Upon removal of this supply, the net groundwater balance dropped from +26.10 thousand acre feet (t.a.f.) to -76.30 t.a.f. – a drop of 102.4 t.a.f (Figure 7). This is approximately equal to receiving 70% more rain on the Niles Cone Basin area, or receiving 26.5% more rain in the entire Alameda Creek Watershed during the period of study. This demonstrates the extent of dependence on Delta water for maintaining net positive groundwater balance from the perspective of the Alameda Creek Watershed and the rainfall it received during the period of study.

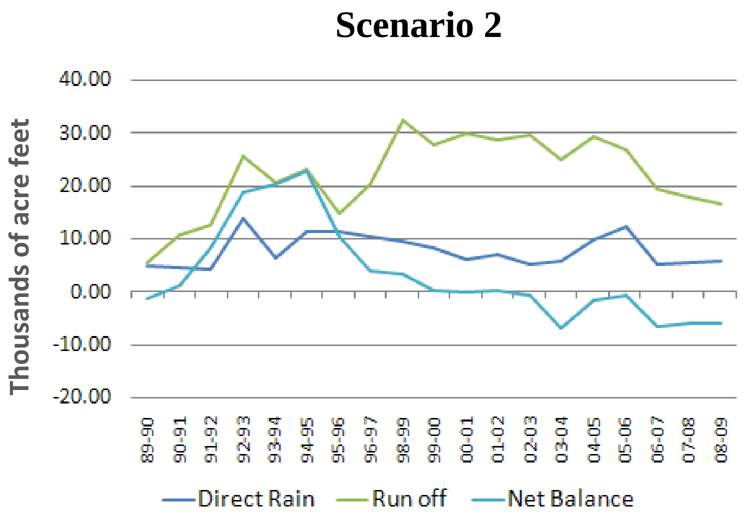
Scenario 2. Calculating the net water balance in the absence of wet year of 1997-98 yielded equally interesting results. Removal of this one year made the net groundwater balance in Niles Cone Basin drop from +26.1 t.a.f. to -6.00 t.a.f. – a drop of 32.1 t.a.f (Figure 8). The year of 1997-98 supplied 58 t.a.f. for recharge, and this is equivalent to 38.8% of the total rain received in the Niles Cone Basin area in the other 19 years, or 13.8% of the total rain received over the entire Alameda Creek Watershed over the other 19 years. Even more surprisingly the year of 1997-98 supplied about half as much (48.8%) water as was obtained from the Delta in the entire 20 year period.

Scenario 3: For this scenario, I first calculated the median rainfall for the region based on the 115 years of historical data that is available and this was 22.98”. This is 45% of the rainfall received in 97-98. I then replaced the recharge input values for 97-98 with a figure that was 45% of the actual value, thereby substituting the outlier year with median year values. This reduced the net water balance from +26.1t.a.f. to -5.68t.a.f. which is quite close to the value seen in scenario 2 (Figure 9).This can be attributed to the fact that although the availability of recharge water in 97-98 was reduced to median year level, the water extraction data for 97-98 was untouched.



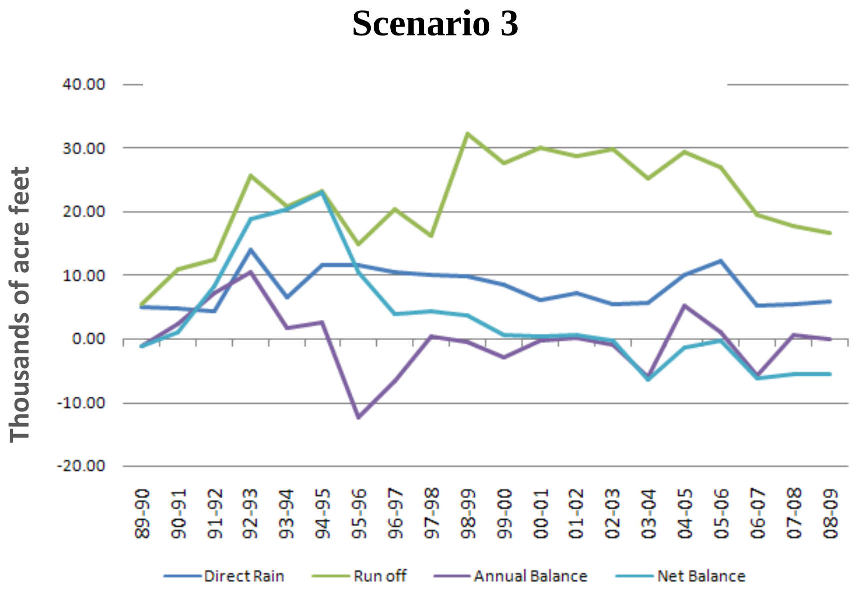
Scenario 1

Figure 7: Impact of removing recharge supply from the Delta via the South Bay Aqueduct



Scenario 2

Figure 8: Impact of removing the outlier year of 97-98 from the dataset.



Scenario 3

Figure 9: Impact of substituting water recharge data based on median rainfall year in place of 97-98 data.

4.0 DISCUSSION

The results show the extent of dependence on Delta water for recharge efforts in the Niles Cone Groundwater Basin. But the most interesting result is the persistent effect of the outlier year of 1997-98 in maintaining net positive groundwater levels. The effect of this outlier year demonstrates how one exceptional year out of the 20 years can make the aquifer net water positive over this period.

The important question that this raises is of the frequency of such outlier events. For instance it could be conjectured that if the region consistently receives one such season of rain every 20 years, the aquifer could potentially be maintained with a net positive water balance over the long term. Based on 115 years of data obtained for the Central Coast region, we can see that 97-98 is the wettest water year on record. I did a recurrence interval analysis to identify the 20 year maxima that we can expect. This was calculated to be approximately 37.59” which is 26.3% lesser than the 97-98 rainfall.

Using this information I developed a fourth scenario where I substituted this reduced rainfall data in place of the outlier year of 97-98. This caused a drop in net water balance from +26.1 t.a.f. to 10.89t.a.f. (Figure 10). This means that when the rainfall was reduced by 26.3%, the net water balance dropped by 58.3%.

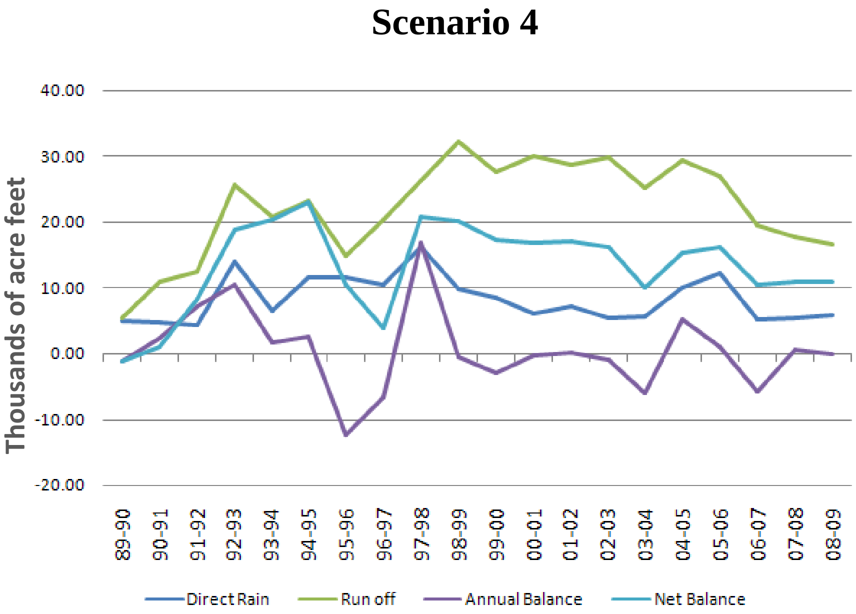


Figure 10: Impact of substituting water recharge data based on average 20 year maxima in place of 97-98 data.

5.0 CONCLUSIONS

In spite of the complex water transfer system prevalent in California, based on this study, I conclude that the groundwater level in the Niles Cone Basin is very much dependent on outside sources like the South Bay Aqueduct as well as fluctuations in precipitation. As can be seen from the data I have analyzed, over the 20 year period from 1989 to 2009, the basin has been able to maintain a net positive water balance as a result of the exceptionally wet year of 1997-98 which happens to be the wettest year since precipitation records were maintained for the region 115 years ago. A recurrence interval analysis of the historical precipitation shows that the expected 20 year maxima is 26.3% less than the rainfall received in 97-98.

Based on the available data and the analysis presented in this paper, I can draw three main conclusions for three different climate change scenarios. The first would be a scenario where there is negligible change in precipitation for this region in the future, while the second would be a scenario of increased precipitation and the third of decreased precipitation.

In case of negligible change in precipitation, I conclude that if the rainfall over the next 20 years is relatively similar to average trends, and if extraction continues at present day levels, the Niles Cone Basin will remain net water positive with respect to 1989 levels, but only by about 10-11 t.a.f. This is based on the outlier substitution analysis mentioned earlier.

If climate change is going to increase the occurrence of wet years, the Niles Cone Basin will get more water for recharge, and maybe even give enough reason to expand the conjunctive water management operations, since it is conceptually s simple strategy of diverting and storing water during the high flow season to provide for the dry seasons.

But if climate change results in drier years on average than what we have on record, we can be reasonably certain that the Niles Cone Basin will become net water negative (based on 1989 levels) unless supply from the Delta is increased sufficiently.

Acknowledgements

I would like to thank Evan Buckland of ACWD for providing the water supply/demand inventory data used in this paper and for answering all my queries regarding conjunctive water management in the Alameda County Water District. I would also like to thank Matt Deitch for his assistance in identifying data sources and for valuable comments on the draft version of this paper.

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