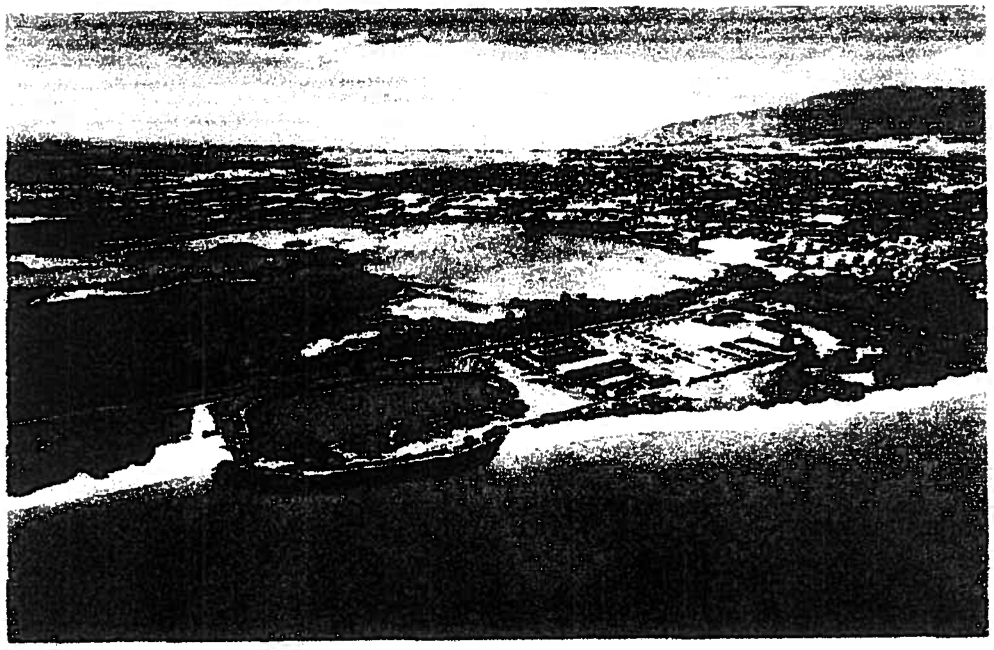
Central Maui Recycled Water

Verification Study



Prepared for:
County of Maui, County Council

Prepared by:
Department of Environmental Management,
Wastewater Reclamation Division

Department of Water Supply
Water Resource Planning Division

December, 2010

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Table 3-1: Option 1 – Properties Served

Property	Estimated Peak R-1 Demand (GPD)	Estimated Cost ($)
Ho'Aloha Park	12,630	–
First Hawaiian Bank	4,000	
Maui Seaside Hotel	15,800	–
Maui Beach Hotel*	19,850	–
Boys & Girls Club of Maui	32,500	–
Maui UH College*	94,730	–
Maui Botanical Gardens	18,950	–
War Memorial Complex*	63,150	–
Ke'Opulani Park*	360,000	–
Ka'ahumanu Avenue Median	25,260	–
Ka'ahumanu Center	44,200	–
Kaiser Permanente Wailuku	6,000	–
Maui Police Department	6,000	–
Kaiser Permanente Maui Lani	6,000	–
Baldwin High School	20,000	–
Dunes at Maui Lani Golf Course*	1,100,000	–
Maui Lani Park & Common Areas**	170,500	–
Total Option 1	**1,999,570**	**$24,022,000**

*Currently utilizes brackish water.
** Future project with planned use of brackish water

Option 2: Develop Distribution System from Kahului WWRF to Kanaha Beach Park and Kahului Airport.

This option should be developed only after the core distribution components identified in Option 1 are completed. R-1 water storage both at the Kahului WWRF and at the elevated location in the vicinity of the Maui Lani Development is required before Option 2 is feasible. This option consisting of approximately 7,800 linear feet of pipe line would extend from the Kahului WWRF to the Kanaha Beach Park and Kahului Airport entrance road area. **Table 3-2** lists the projects that could be provided with R-1 water and the estimated construction cost with Option 2.

Table 3-2: Option 2 – Properties Served

Property	Estimated Peak R-1 Demand (GPD)	Estimated Cost ($)
Kanaha Beach Park	157,900	–
Kahului Airport & Access Road	67,000	–
Total Option 2	**224,900**	**$3,972,000**

SHORT COMMUNICATION

THE EFFECT OF PLANT RESIDUE LAYERS ON WATER USE AND GROWTH OF IRRIGATED SUGARCANE

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Abstract

The industry is under pressure to use water more efficiently. One way of achieving this is through the retention of a layer of plant residues to reduce wasteful evaporation from the soil. However, a residue layer could also inhibit crop growth. This communication reports on the results obtained from a field experiment conducted at Pongola on three weighing lysimeters, to measure the impact of residue layers on crop water use, canopy development, crop growth and final yield.

Keywords: plant residue, trash, water use, irrigation, evapotranspiration, stalk population, canopy development

Introduction

The South African sugar industry is under pressure to demonstrate that limited water resources are being used efficiently. One way of achieving this is through the retention of a layer of plant residues from the previous crop to reduce wasteful evaporation from the soil surface. Other reported advantages of such a cropping system include improved soil health and better weed control (de Beer *et al*, 1995). Reported disadvantages include reduced crop growth rate and yield (Gosnell and Lonsdale, 1978) higher harvesting and transport costs and an upsurge of insect pests (Meyer *et al*, 2005). The change to a system of retaining crop residues has therefore been slow among farmers, and as a result, only 20% of the cane in KwaZulu-Natal and less than 5% in Mpumalanga is harvested as green cane.

The objective of this study was to determine the effect of different types of residue layers on (i) crop growth, (ii) water use and (iii) cane yield of fully irrigated sugarcane. This information could be used to improve the ability of crop models to accurately simulate crop growth and water use in a residue layer cropping system. It could also assist in formulating best irrigation management practices for profitable and sustainable sugarcane production.

Methods

A field trial was conducted at the South African Sugarcane Research Institute (SASRI) research station at Pongola on a trial site that contained three weighing lysimeters, each 2.44 m long, 1.52 m wide and 1.22 m deep. Cultivar N14 was planted on 24 April 2004 in rows 1.4 m apart in a Hutton soil containing 30% clay. Lysimeters, as well as the area surrounding each lysimeter, had (i) no residue cover (Bare), (ii) soil covered by a light layer

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of cane tops (Tops) or (iii) soil covered by a heavy layer of tops and dead leaves (Trash). Plant residue layers were applied one month after germination at a rate of 8.3 t/ha (14 cm thick) for Trash and 1.8 t/ha (10 cm thick) for Tops. Hourly changes in weight of individual lysimeters were detected electronically (to the nearest 0.1 mm) via load cells (Route Calibration Services) connected to a CR10X (Campbell Scientific Inc.) data logger. Tipping bucket rain gauges (Texas Instruments) measured deep drainage under each lysimeter. Lysimeters were irrigated individually according to demand, on reaching a deficit of 20 mm as indicated by lysimeter readings. A watering can was used to apply exact irrigation amounts and to mimic an overhead irrigation system. The cane fields surrounding the lysimeters were irrigated with a drip irrigation system according to the Canesim program (Singels *et al*, 1998) and weather data.

Stalk population, stalk height and fractional interception of photosynthetic active radiation (measured with a model PAR-80 Ceptometer, Decagon Devices, Pullman, WA, USA) were determined biweekly. At harvest (12 months of age) cane yield was determined and the total crop water use calculated. To account for the effect of crop characteristics on crop water requirements, crop coefficients (Kc) were calculated to relate reference crop evapotranspiration (ET_0) to crop evapotranspiration (ET_{crop}) according to FAO 56 guidelines (Allen *et al*, 1998). ET_{crop} was calculated as the daily change in lysimeter mass (converted to mm water), plus irrigation (mm), minus deep drainage (mm). Suspect data, e.g. negative ET_{crop} values, were removed from the dataset.

Results and Discussion

Crop growth

Plant residue layers had a negative effect on rate of canopy development and crop growth. The Bare treatment reached 80% radiation capture 20 days before the Tops treatment and 45 days before the Trash treatment (Figure 1). Thermal times (base 16) required to reach 50% and 80% radiation capture for the Bare, Tops and Trash treatments were 267, 481 and 622°Cd and 622, 815 and 1046°Cd respectively. All treatments, however, intercepted close to 100% of the radiation towards the end of the growing season. Wood (1991) reported similarly that a residue layer could have a negative effect on the crop by slowing down initial growth, tillering and radiation interception due to lower soil temperatures.

Cane stalks of the Tops and Trash treatments were slightly shorter than those of the Bare treatment throughout the growing season. Peak tiller population of the Tops and Trash treatments were reduced by 38% when compared with those of the Bare treatment. Final stalk population was, however, similar for all three treatments, namely 23 stalks/m^2.

Although both residue treatments reduced final cane yield by an average of 14%, yields were not statistically different from that of the Bare treatment (125 t/ha). A similar, but less pronounced trend was observed in cane grown on the areas surrounding the lysimeter scales. Significant yield responses to residue blankets have been reported for rainfed cane by Wood (1991) (10 t/ha), van Antwerpen *et al.* (2001) (9.3 t/ha) and for low rainfall areas by de Beer *et al.* (1995).

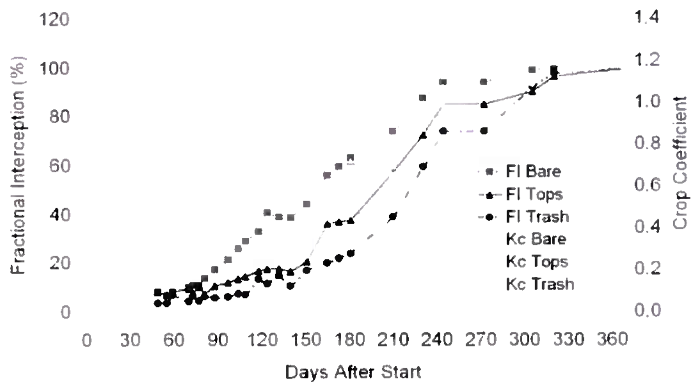

Figure 1. Fractional interception (FI) of photosynthetic active radiation as affected by different residue layers. Corresponding crop coefficients (Kc values) for the FAO 56 methodology (Allen *et al*, 1998) are represented by the open symbols.

Crop water use

The presence of residue layers had a marked effect on daily average crop water use, especially in the period leading up to full canopy closure. During this period, daily average crop water use in the Tops treatment was reduced by an average of 22%, and that of the Trash treatment by 40%, compared with the Bare treatment (data not shown). After full canopy closure, daily crop water use of all treatments was fairly similar. As a result, seasonal crop water use was reduced by 16% and 25% for the Tops and Trash treatments respectively (Figure 2). A significant amount of drainage was measured in the Trash treatment. This was partly due to over-irrigation on a few occasions. Thorburn *et al*, (1999) indicated that a residue blanket could reduce soil water evaporation by an amount equal to 16% of annual rainfall.

Crop coefficients for the period of partial canopy differed significantly between treatments, and hence irrigation scheduling needs to account for this. Crop coefficients calculated for use in a crop residue system were much lower than for the bare soil scenario (Figure 1). The value of 1.2 for the mid-growth phase of bare soil is in general agreement with results obtained by Inman-Bamber and McGlinchey (2003).

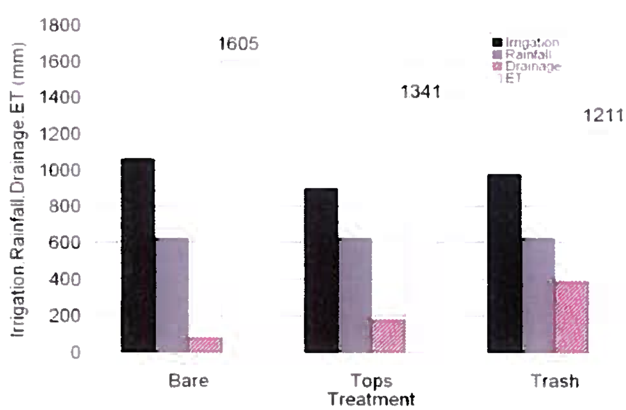

Figure 2. Seasonal water balance for a 12-month old plant crop grown in Pongola, as affected by different crop residue layers.

General

It is noteworthy that, despite the reduction in initial growth and radiation interception under residue layers, the crop recovered towards the end of the growing season so that no significant yield loss was observed. The biggest impact was on the reduction of evaporation from the soil surface, that ultimately resulted in reduced seasonal crop water use. It is vital that normal irrigation scheduling practices be adjusted to take advantage of these savings.

Conclusions

- Initial crop growth and radiation capture were affected negatively by crop residue layers, but without significantly reducing final cane yield.
- Seasonal crop water use was reduced by 16% and 25% for the Tops and Trash treatments respectively.

These results justify a concerted effort by the industry to further explore the application of green cane harvesting and trash blanketing in irrigated sugarcane production. Results could also be used to improve the ability of the crop models to accurately simulate crop growth and water use in a residue layer cropping system.

Acknowledgements

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REFERENCES

Allen RG, Pereira LS, Raes D and Smith M (1998). Crop evapotranspiration – guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, FAO, Rome.

de Beer AG, Hudson C, Meyer E and Seigmund B (1995). Green cane harvesting and trash management. *Proc Int Soc Sug Cane Technol* 22: 133-141.

Gosnell JM and Lonsdale JE (1978). Effects of irrigation level and trash management on sugarcane: Part II. *Int Sug J* 80: 299-303.

Inman-Bamber NG and McGlinchey MG (2003). Crop coefficients and water-use estimates for sugarcane based on long-term Bowen ratio energy balance measurements. *Field Crops Res* 83: 125-138.

Meyer E, Norris CP, Jacquin E, Richard C and Scandaliaris J (2005). Burnt versus green cane harvesting: Agricultural engineering challenges. *Proc Int Soc Sug Cane Technol* 25: 294-302.

Singels A, Kennedy AJ and Bezuidenhout CN (1998). Irricane: A simple computerised irrigation scheduling method for sugarcane. *Proc S Afr Sug Technol Ass* 72: 117-122.

Thorburn PJ, Robert ME, Lisson S, Wood AW and Keating BA (1999). Impacts of trash retention on soil nitrogen and water: An example from the Australian sugar industry. *Proc S Afr Sug Technol Ass* 73: 75-79.

van Antwerpen R, Meyer JH and Turner PET (2001). The effects of cane trash on yield and nutrition from the long-term field trial at Mount Edgecombe. *Proc S Afr Sug Technol Ass* 75: 235-241.

Wood AW (1991). Management of crop residues following green harvesting of sugarcane in north Queensland. *Soil Till Res* 20: 69-85.

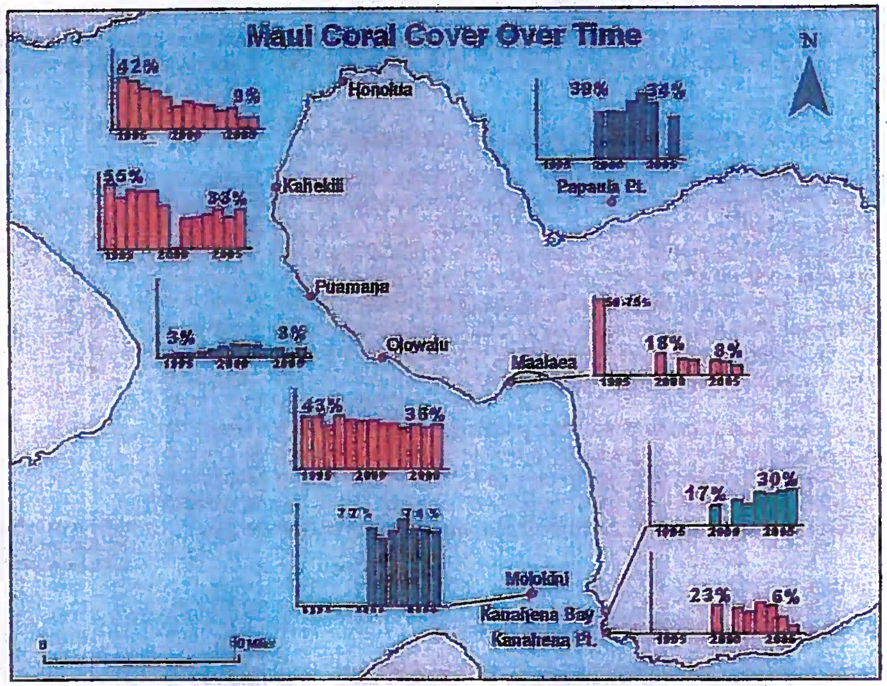
Status and Trends of Maui's Coral Reefs

In 1999, The Hawaii Division of Aquatic Resources (DAR) in partnership with the Coral Reef Assessment and Monitoring Program began annual surveys of coral condition at 9 reef areas in Maui County (see map ↓). The 4 West Maui stations had been previously monitored by the Pacific Whale Foundation since 1994. Those long-term monitoring programs provide an opportunity to assess the status and trends of Maui's coral reefs over the last 7 to 13 years.

Coral Status and Trends

- Coral cover in 2006 ranged from 74% at Molokini to <10% at 4 sites: Honolua (9%), Puamana (8%), Maalaea (8%), and Kanahena Pt (6%).
- Coral cover increased at only 1 reef (Kanahena Bay, 17% to 30%), remained stable (<5% change), at 3 reefs (Molokini, Papaula Point, and Puamana), and declined at 5 reefs, most dramatically at Honolua (42% to 9%) and at Kahekili (55% to 33%).
- Mean coral cover of the 9 reefs declined from 35% when sites were first surveyed (1994 for West Maui, 1999 elsewhere) to 27% in 2006. Thus, nearly ¼ of all living coral was lost over that period.

Given the strong likelihood that several of the sites were already somewhat degraded when monitoring began, recent trends almost certainly underestimate declines over longer timeframes. For example, coral cover at the Maalaea site declined from 18% to 8% between 1999 and 2006, but a 1993 Fish & Wildlife Service study estimated coral cover there as being between 50% and 75%.



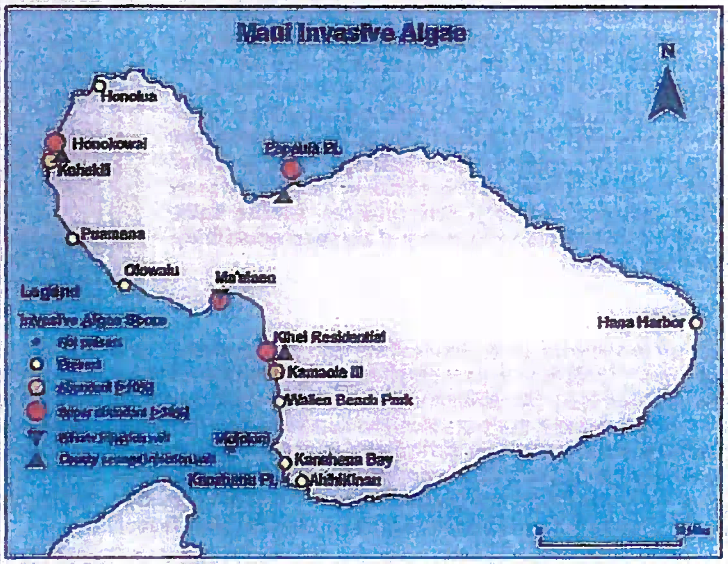
Trends in coral cover at 9 long-term monitoring stations. Red indicates >5% decline over monitoring period, green indicates >5% increase, black = no change (<5%)

The causes of coral reef decline around Maui are complex and vary among locations, but there are strong indications that human impacts have been very important. Notably, cover has declined at several West Maui sites: Honolua Bay, Kahekili, shallow reefs of Olowalu, and at Maalaea, where anthropogenic impacts from shoreline development and human use are likely greatest. Conversely, sites which have experienced increases or sustained high coral cover are remote or offshore (Kanahena Bay and Molokini). The one observed decline on a relatively remote reef (at Kanahena Point since 2004) was due to a local outbreak of the coral-eating crown-of-thorns starfish.

The Growing Problem of Invasive Algae

A significant and growing concern is the increasing overgrowth of reefs by invasive seaweeds, particularly *Acanthophora spicifera, Hypnea musciformis and Ulva* spp.. Shallow reefs in Kihei and Maalaea are now almost totally overgrown by those species and *A. spicifera* has become much more abundant in recent years at other locations including Honokowai/Kahekili and Papaula Point. Algal blooms are indicative of a loss of balance between factors which promote algal growth (e.g. nutrient availability) and those which control algal abundance (e.g. grazing). It is likely that both high nutrients & low grazing have been important:

- Studies by researchers from University of Hawaii (UH, next page), together with the evident correspondence between reefs with severe algal blooms and coastal areas with high human population density (see →), strongly suggest that elevated nutrients from wastewater or fertilizers are fueling accelerated algal growth.
- Reefs with abundant herbivorous fishes, such as those in the Honolua and Molokini MLCDs, have little or no invasive algae present, whereas reefs with depleted herbivore populations (e.g. Maalaea) are severely overgrown by algae.



Distribution of invasive algae around Maui: 'present' means invasive species found only in low abundance & in limited habitats, 'abundant' indicates cover of 10-30% on extensive portions of reef; 'super-abundant' means >30% algal cover in multiple reef zones

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Using $\delta^{15}N$ values in algal tissue to map locations and potential sources of anthropogenic nutrient inputs on the island of Maui, Hawai'i, USA

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ABSTRACT

Macroalgal blooms of *Hypnea musciformis* and *Ulva fasciata* in coastal waters of Maui only occur in areas of substantial anthropogenic nutrient input, sources of which include wastewater effluent via injection wells, leaking cesspools and agricultural fertilizers. Algal $\delta^{15}N$ signatures were used to map anthropogenic nitrogen through coastal surveys (island-wide and fine-scale) and algal deployments along nearshore and offshore gradients. Algal $\delta^{15}N$ values of 9.8‰ and 2.0–3.5‰ in Waiehu and across the north-central coast, respectively, suggest that cesspool and agricultural nitrogen reached the respective adjacent coastlines. Effluent was detected in areas proximal to the Wastewater Reclamation Facilities (WWRF) operating Class V injection wells in Lahaina, Kihei and Kahului through elevated algal $\delta^{15}N$ values (17.8–50.1‰). From 1997 to 2008, the three WWRFs injected an estimated total volume of 193 million cubic meters (51 billion gallons) of effluent with a nitrogen mass of 1.74 million kilograms (3.84 million pounds).

1. Introduction

Anthropogenic nitrogen (N) loading to the nearshore marine environment through sewage and fertilizer runoff are known to increase primary productivity in coastal systems (Doering et al., 1995; Taylor et al., 1999; Thornber et al., 2008). In extreme cases, excess nutrient loading in coastal regions has resulted in the formation and proliferation of large scale opportunistic macroalgal blooms (Brittany France, Briand, 1989; Puget Sound Washington USA, Thom and Albright, 1990; Venice Lagoon Italy, Sfriso et al., 1993; Jamaica and southeast Florida USA, Lapointe, 1997; Paerl, 1997; Valiela et al., 1997; Ebro River Delta Spain, Menendez and Comin, 2000; Ythan Estuary Scotland, Raffaelli, 2000; Kaneohe Bay Hawaii USA, Stimson et al., 2001; Lapointe et al., 2005; Morand and Merceron, 2005; Sacca di Goro Italy, Viaroli et al., 2005; southeastern Gulf of California USA, Pinon-Gimate et al., 2009). Ecosystem impacts of large scale algal blooms include diminished water column oxygen levels, negative effects on seagrass beds, fisheries and benthic community composition and increased microbial abundance (Barnes, 1973; Johannes, 1975; Smith et al., 1981; Rosenberg, 1985; Burkholder et al., 1992; Zaitsev, 1992; Alber and Valiela, 1994; Morand and Briand, 1996; McCook, 1999; Raffaelli, 2000).

Sources of additional N entering the ocean are often difficult to detect with many water quality assessment tools (ambient nutrient and salinity measurements) because the ocean is a dynamic environment where currents, wave activity and general mixing events can rapidly dilute potentially elevated nutrient levels. Additionally biological uptake of nutrients may occur at rates similar to input rates making the detection of nutrient flux extremely difficult. The United States Environmental Protection Agency (US EPA) recommends the use of bioassays, biological and habitat data in addition to chemical data for water quality assessments (US EPA, 2002). The use of natural stable isotopes of N (^{15}N:^{14}N, expressed as $\delta^{15}N$) to distinguish between natural and sewage derived N is well established (see Risk et al., 2009 for a recent review) because natural (atmospheric) and fertilizer N sources have generally low signatures (ranging from 0–4 and −4 to 4‰, respectively, (Owens, 1987; Macko and Ostrom, 1994)). Sewage N is enriched in ^{15}N because bacteria preferentially use ^{14}N (Heaton, 1986) thereby elevating sewage derived wastewater in ^{15}N relative to ^{14}N. The extent of ^{15}N enrichment in sewage is therefore dependant upon on the level and type of treatment (i.e. the greater the denitrification via bacterial activity the higher the $\delta^{15}N$ value). Consequently, sewage derived $\delta^{15}N$ values in the literature from various sources of sewage range from 7‰ to 38‰ (Kendall, 1998; Gartner et al., 2002; Savage and Elmgren, 2004; summarized in Table 1).

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Table 2 (*continued*)

Region	Collection site	*Ulva fasciata*	*Asteronema breviarticulatum*	*Hypnea musciformis*	*Ahnfeltiopsis concinna*
	Keanae Point E				X
	Keanae Point W		X		
	Koki N		X		
	Koki S		X		X
	Nahiku 1		X		
	Nahiku 2		X		
	Nahiku 3		X		
	Venus Pools		X		
	Wainapanapa 1	X	X		
	Wainapanapa 2		X		X
South Maui	Ahihi Kinau	X			X
	Central Kihei N (Kalama BP)	X		X	
	Central Kihei	X			
	Central Kihei S	X			
	La Perouse 1 E	X	X		
	La Perouse 2		X		X
	La Perouse 3		X		
	La Perouse 4		X		
	La Perouse 5 W	X			
	Makena N	X			
	Makena	X	X	X	
	Makena S	X	X	X	
	Keawakapu BP	X	X	X	
	Wailea N	X	X	X	
	Wailea S	X		X	
	Waipulani BP N	X		X	
	Waipulani BP	X		X	
	Waipulani BP S	X		X	
Northwest Maui	Honokohau		X		
	Honokohau stream	*Cladophora sericea*			
	Kahakuloa		X		
	Punaha Gulch		X		
	Punaha Gulch N	X			
	Punaha Gulch S	X	X		
Southeast Maui	Arches 1		X		
	Arches 2		X		
	Big Kiawae 1		X		
	Big Kiawae 2	X			
	Kaupo 1		X		X
	Kaupo 2		X		

standards and performing TMDL studies) and holds the authority for the National Pollutant Discharge Elimination System (NPDES) permits in Hawai'i.

Most of the residents on Maui live in three main towns (Kahului, Kihei and Lahaina) that are served by centralized regional sewage collection and treatment systems. The County of Maui operates Wastewater Reclamation Facilities (WWRF) that use BNR followed by disposal into Class V injection wells (Parabicoli, pers. comm.) in Kihei (3 IWs), Kahului (8 IWs) and Lahaina (4 IWs). The majority of the injected wastewater at the WWRFs does not receive disinfection treatments (e.g. chlorine or ultra-violet radiation), nor does the SH DOH or US EPA require it at this time. The WWRFs are the three largest wastewater sources on Maui. Many smaller towns along the coastline adjacent to these major population centers use cesspools for sewage disposal. SH DOH and US EPA databases indicate that Maui has >6000 individual small septic or small cesspool wastewater systems (including those in the areas of Waiehu, Waihikuli and Maui Meadows) and more than 300 injection wells including large capacity septic (93) and wastewater treatment plants (59). Small individual sewage treatment plants with IWs are located in Kahului, Makena and Ma'alaea. Ma'alaea, located on the south-central coast, has one commercial and 12 condominium developments each with privately owned sewage treatment facilities and IWs. Ma'alaea also has two direct discharges to surface waters contributing low concentrations of N (from the Maui Ocean Center and Maui Electric Company) that are authorized under NPDES permits. Anthropogenic N loading on Maui also includes fertilizers from extensive agricultural operations that occur in the central portion of Maui between the north and south coast.

Kihei is a highly developed area in South Maui where algal blooms have persisted for decades (Wiltse, US EPA, pers. comm.). The extensive fringing reef adjacent to Kihei generally has poor water circulation so nutrients entering the reef flat are likely to have long residence times and/or be acquired by algae. In contrast, the reef in the Kahekili Beach Park (BP) area (near the Lahaina WWRF) lacks an extensive reef flat and generally has a persistent current flowing to the south (Storlazzi and Field, 2008). The shallow forereef (approximately 1.5–10 m offshore) has had algae blooms (primarily of *U. fasciata*) in the summers, when wave action from the north is diminished (pers. obs.). This area also frequently has bubbles of an unidentified gas flowing from the benthos and warmer-than-ambient-water freshwater seeps. The seeps are consistently present and are surrounded by rocks and coral rubble with black precipitates. The black precipitate is likely iron oxide which arises from anoxic conditions in the groundwater (Bhagat et al., 2004). This reef is located within the Kahekili Herbivore Fisheries Management Area (HFMA) that was established on July 25th 2009 by the State of Hawai'i, Department of Land and Natural Resources, Division of Aquatic Resources (DAR) (http://hawaii.gov/dlnr/dar/regulated_areas_maui.html). The Kahekili HFMA encompasses approximately 3.0 km of coastline and is now closed to the taking of herbivorous fishes and sea urchins in efforts to restore a healthy grazing population to combat excessive algal growth associated with the decadal documentation of coral decline (SH DLNR, 2006).

The SH DOH has reported to the US EPA and US Congress that the water quality in several coastal segments of Maui in the vicinity of the WWRFs, injection wells and injectate plumes are not meeting state water quality standards. Water quality impairments reported for the Kahekili area were due to exceeded water quality criteria for water column concentrations of Total Nitrogen (TN), Chlorophyll *a*, and Ammonia (Honokowai Point to Kaanapali), Total Phosphorous (TP) and turbidity (Honokowai BP) and turbidity at Kahekili BP. In addition, 19 coastal segments along the developed Kihei coast and three coastal segments of Kahului Harbor are currently listed as impaired for various combinations of pollutants including TN, Nitrite–Nitrate, Ammonia, TP, Chlorophyll *a* and turbidity. One segment of Kahului Harbor is listed as impaired due to exceedances of bacterial criteria (*Entercoccci*) (SH DOH, 2006).

3. Material and methods

3.1. Island-wide coastline survey

In the summer of 2007, an island-wide survey of intertidal algal $\delta^{15}N$ values from all accessible coastlines on Maui was conducted to locate areas and potentially identify sources of anthropogenic N enrichment. Maui has approximately 190 km of coastline with the majority of the population residing in a few discrete regions (Kahului, Waiehu, Kihei, Maalaea, Lahaina, Kaanapali, Kahana and Napili). Survey intervals occurred every 1.5 km in populated areas and every 8 km in unpopulated areas. Where possible, three sites 0.3 km apart were sampled per survey interval, intertidal macroalgae were sampled in triplicate per genera and two to three genera were collected when possible (from 45 sites, Table 2, Fig. 1a–f). The following macroalgae were collected during the survey: *Acanthophora spicifera*, *Ahnfeltiopsis concinna*, *Asteronema breviarticulatum*, *Cladophora sericea*, *H. musciformis*, and *U. fasciata* (Table 2). Using this approach, a total of 116 sites and 516 samples were collected around Maui; 21 km of coastline were inaccessible by foot due to treacherous terrain.

3.2. Fine-scale mapping survey

This survey aimed to identify the presence of sewage N along the coastline in areas with elevated $\delta^{15}N$ values and high recreational uses (Kahekili and Kalama BPs). All sampling occurred in the intertidal zone; sites extended along approximately 1.2 km of coastline centered on the highest $\delta^{15}N$ values found from the coastal survey (above) for Kahekili BP (near the Lahaina WWRF) and Kalama BP (adjacent to the Kihei WWRF) (Fig. 2). Naturally occurring, attached samples of *U. fasciata* were collected for $\delta^{15}N$ analyses (in triplicate per site, $n = 81$ and 96 for Kahekili and Kalama BPs, respectively) from sites approximately 100 m apart for the first five sites in the north, then every 50 m for the remainder of the sites to the south for Kihei; in Lahaina the last three southerly sites were 100 m apart (Fig. 2).

3.3. Mapping the Lahaina WWRF effluent plume with deployed algae

To determine the extent to which the effluent plume from the Lahaina WWRF stretched across the adjacent coral reef, we employed an approach similar to Costanzo et al. (2001), however we deployed samples of *U. fasciata* ($n = 96$ per deployment) 0.5 m from the benthos. In January 2009, 32 semi-permanent

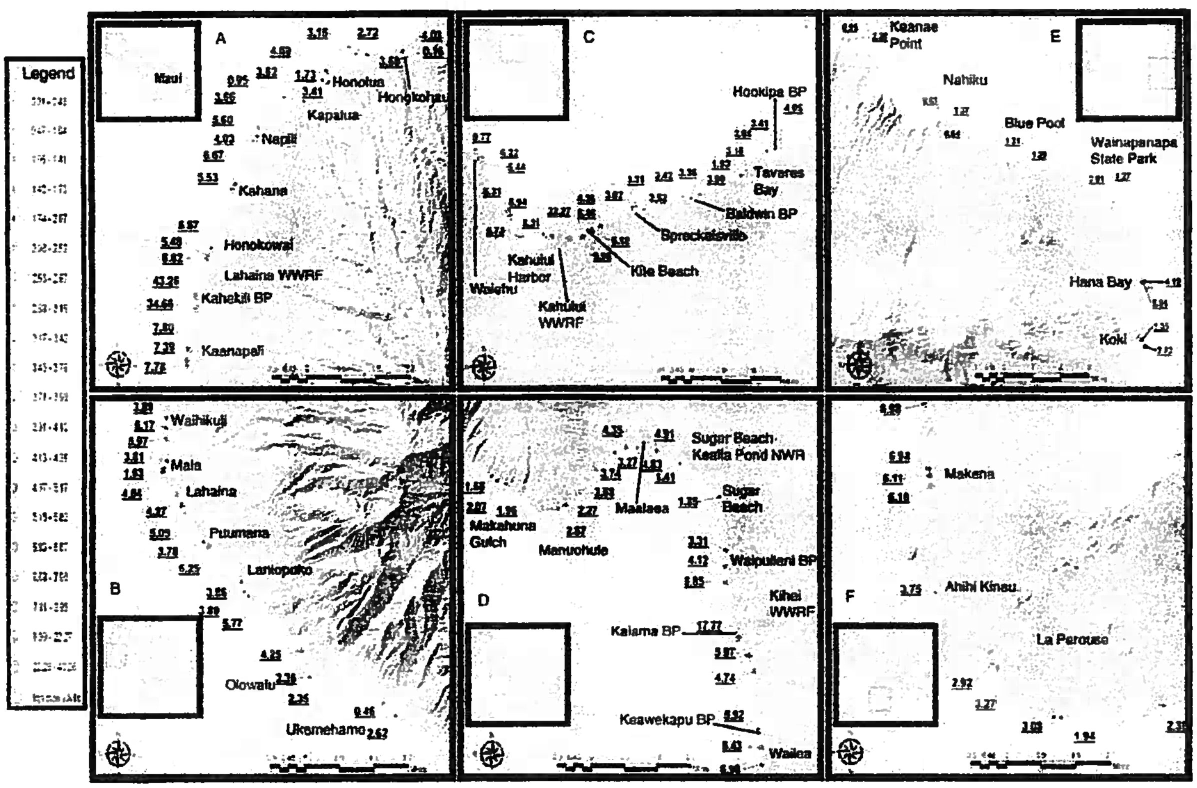

Fig. 1. Island-wide algal collection sites and associated average algal $\delta^{15}N$ values from the northwest (a), southwest (b), north-central (c), south-central (d), northeast (e) and southeast (f) regions of Maui. Injection well locations are represented by red triangles.

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exempted from NPDES permitting). CWA Section 401 requires the applicant for a federal permit that would conduct any activity that may result in "any discharges into navigable waters" to obtain a State certification that any discharge allowed by the federal permit meets the technology based effluent standards, water quality standards, water quality based effluent limits, pre-treatment effluent and toxic standards. Section 403 establishes specific guidelines for NPDES discharges into territorial seas and waters of the contiguous zone (oceans), specifying that there be "no unreasonable degradation of the marine environment". NPDES permits implement minimum wastewater treatment standards through the imposition of technology based effluent limits with more restrictive water quality based effluent limits if discharges meeting technology based effluent limits might cause or contribute to exceedances of surface water quality standards. These CWA requirements often result in more restrictive effluent limits (requiring more treatment for pollutant removal) than would be required under a UIC permit. For example, the Maui Ocean Center NPDES discharge is limited to 3.1 kg (7 lbs) d^{-1} of TN, and is subject to further reductions if needed under a TMDL; whereas the County of Maui WWRF UIC permits do not limit the mass discharge of nitrogen and currently inject mass loads estimated to range from 79 to 207 kg (131–457 lbs) d^{-1} of TN. Implementation of pollutant load reduction to meet TMDL allocation is mandatory for discharges authorized under NPDES permits, whereas attainment of allocations for other sources, such as injection wells under federal UIC permits and permit-exempted nonpoint sources, is implemented through voluntary and incentive based programs.

Although injection wells discharge pollutants and are considered point sources under the CWA (40 CFR Part 122.2), NPDES permits have not typically been required because the definition of "Waters of the US" under the CWA does not explicitly include groundwater; jurisdiction has been based largely on the interpretation of the term "navigable waters". Recently a number of courts have held that the NPDES permit requirements of the CWA potentially apply even to the indirect discharge of a pollutant into navigable waters where there is "a connection or link between discharged pollutants and their addition to navigable waters" or significant nexus between source and impact (Rapanos v. US, 547 US 715 (2006); Northern California River Watch v. City of Healdsburg, 457 F.3d 1023, 496 F.3d 993 (9th Cir. 2007); http://www.epa.gov/region/water/groundwater/uic-pdfs/lahaina02/Jeff_SchwartzComments).

6. Implications

This work demonstrates the usefulness of algal $\delta^{15}N$ values to distinguish between natural and anthropogenic derived N and to identify the spatial extent of algal blooms that are incorporating anthropogenic derived N sources. The method was identified as an assessment tool with potential for use by the State of Hawai'i's ongoing Integrated Water Quality Reporting to Congress (SH DOH, 2009). Perhaps more importantly from a management perspective, this work provides a significant nexus between a wastewater source injected into the groundwater and specific surface water quality impacts that prevent the attainment of protected uses such as the conservation of coral reefs and support of aquatic life. Given recent court rulings, the establishment of this connection might lead to a determination that injection wells should be required to have NPDES permits in addition to UIC permits. NPDES permits are mandated to include provisions not required under UIC permits including water quality based limits, and compliance with TMDLs and the ocean discharge criteria under CWA Section 403, whereas the SDWA does not require the consideration of impacts to receiving water uses other than drinking water. Where there is significant nexus to navigable waters, governing authorities should assure that any federal authorization to discharge wastewater, including UIC permits, have a CWA Section 401 certification that the permit conditions are in compliance with the requirements for minimum treatment standards, water quality standards, and water quality based effluent limitations where warranted. With or without an NPDES permit, these releases are a source of nitrogen loading that will be addressed by a TMDL in impaired waters receiving injectate. Releases from injection wells, with or without NPDES permits, cannot lawfully be allowed to cause or contribute to violations of water quality standards, degradation of aquatic ecosystems and non attainment of legally protected beneficial uses.

Acknowledgements

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References

Alber, M., Valiela, I., 1994. Production of microbial organic aggregates from macrophyte-derived dissolved organic material. Limnology and Oceanography 39, 37–50.

Barile, P.J., 2004. Evidence of anthropogenic nitrogen enrichment of the littoral waters of East Central Florida. Journal of Coastal Research 20, 1237–1245.

Barile, P.J., Lapointe, B.E., 2005. Atmospheric nitrogen deposition from a remote source enriches macroalgae in coral reef ecosystems near Green Turtle Cay, Abacos, Bahamas. Marine Pollution Bulletin 50, 1265–1272.

Barnes, E.S., 1973. Sewage pollution from tourist hotels in Jamaica. Marine Pollution Bulletin 4, 102–105.

Bhagat, M., Burgess, J.E., Antunes, P.M., Whiteley, C.G., Duncan, J.R., 2004. Precipitation of mixed metal residues from wastewater utilizing biogenic sulfide. Minerals Engineering 17, 925–932.

Briand, X., 1989. Proliferation de l'algue verte Ulva sp. en baie de Lannion (France): etude d'une nuisance et de son taitement par fermentation anaerobe These de 3eme cycle: Biologie et Physiologie Vegetale., VII. University of Lille I. +210 pp.

Burkholder, J.M., Mason, K.M., Glasgow Jr., H.B., 1992. Water-column nitrate enrichment promotes decline of eelgrass *Zostera marina*: evidence from seasonal mesocosm experiments. Marine Ecology Progress Series 81, 163–178.

Chaves, J., 2004. Potential Uses of $\delta^{15}N$ to Assess Nitrogen Sources and Fate in Narragansett Bay. Ph.D. Dissertation, University of Rhode Island, Narragansett.

Cohen, R., Fong, P., 2005. Experimental evidence supports the use of $\delta^{15}N$ content of the opportunistic green macroalga *Enteromorpha intestinalis* (Chlorophyta) to determine nitrogen sources to estuaries. Journal of Phycology 41, 287–293.

Cole, M.L., Valiela, I., Kroeger, K.D., Tomasky, G.L., Cebrian, J., Wigand, C., McKinney, R.A., Grady, S.P., Carvalho de Silva, M.H., 2004. Assessment of an $\delta^{15}N$ isotopic method to indicate anthropogenic eutrophication in aquatic ecosystems. Journal of Environmental Quality 33, 124–132.

Costanzo, S.D., O'Donohue, M.J., Dennison, W.C., Loneragan, N.R., Thomas, M., 2001. A new approach for detecting and mapping sewage impacts. Marine Pollution Bulletin 42, 149–156.

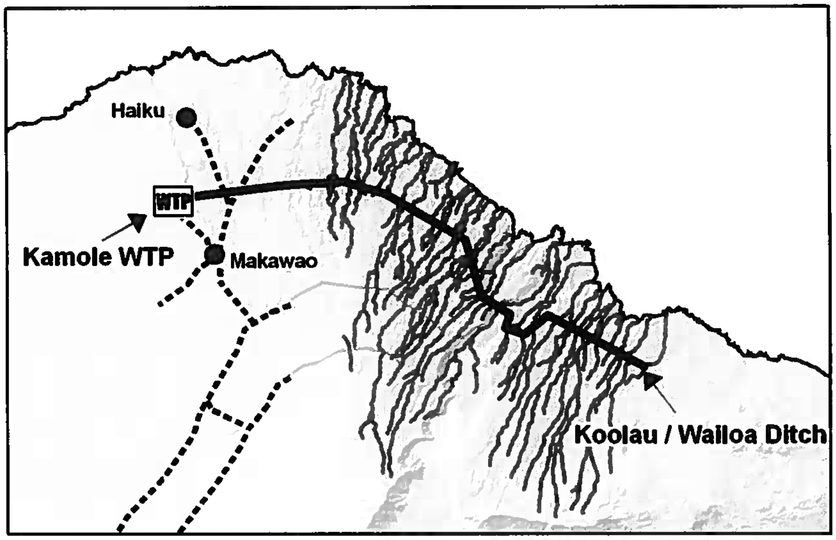
Costanzo, S.D., O'Donohue, M.J., Dennison, W.C., 2004. Assessing the influence and distribution of shrimp pond effluent in a tidal mangrove creek in north-east Australia. Marine Pollution Bulletin 48, 514–525.

Costanzo, S.D., Udy, J., Longstaff, B., Jones, A., 2005. Using nitrogen stable isotope ratios ($\delta^{15}N$) of macroalgae to determine the effectiveness of sewage upgrades: changes in the extent of sewage plumes over four years in Moreton Bay, Australia. Marine Pollution Bulletin 51, 212–217.

Dailer, M.L., Smith, C.M., submitted for publication. Investigating the ecophysiological response of native and invasive macroalgae in Hawaii to macro and micro nutrients in secondarily-treated sewage effluent. Marine Ecology Progress Series (in review).

Appendix C

Impacts of Amended Interim Instream Flow Standards on Drought Period Reliable Capacity of the Kamole Water Treatment Plant



Summary

Amendments to the Interim Instream Flow Standards (IIFS) for East Maui streams will result in decreased water flows available to the Kamole Water Treatment Plant (WTP) in dry months and drought conditions. Actions will be necessary by the Maui Department of Water Supply (DWS) to mitigate the impacts of decreased water supply in order to maintain the existing drought period reliable capacity of the Kamole WTP.

The Kamole WTP provides treated potable water for the DWS Upcountry District water system. The DWS now relies on the Kamole WTP to provide at least 4.5 MGD of potable water to the Upcountry District system in dry months and drought periods. This minimum drought period reliable capacity is limited by the existing flow characteristics of the Wailoa Ditch and the physical WTP intake structure configuration.

Possible actions to maintain the existing drought period reliable capacity now provided by the Kamole WTP include (1) construction of a raw water strorage reservoir, (2) construction of a series of basal groundwater wells to provide an alternate source of drought period reliable capacity or (3) contractual arrangements with A&B/EMI regarding use of available Wailoa Ditch water or use of existing DWS or HC&S groundwater wells to supplement Hamakua Ditch flows.

Economic analysis indicates that the cost to mitigate decreased drought period capacity of the Kamole WTP using groundwater basal wells to provide alternate drought period capacity is $7 to 8 million for each 1 MGD impact up to $32 to 36 million to mitigate the full existing 4.5 MGD drought period reliable capacity. The cost to build a raw water storage reservoir to maintain existing Kamole WTP drought period reliable capacity would depend upon several uncertain factors, including the magnitude of reductions to the Wailoa Ditch base flow and reservoir construction costs, roughly estimated in the range of $15 to 60 million.

Impacts of IIFS Releases on Wailoa Ditch Flow

The source of water for the Kamole WTP is the Wailoa/Koolau Ditch system which transports water diverted at elevations above 1100 feet from a series of East Maui streams to the Kamole Weir. Water from Kamole Weir is used to supply the Kamole WTP and also feeds the Hamakua Ditch which is used to irrigate sugar cane and supplies the Kula Agricultural Park. Some water from Kamole Weir is dropped to the lower elevation Lowrie Ditch system through a penstock to provide hydroelectric power.

Recently, responding to a petition to amend the IIFS on 27 East Maui streams, the Commission on Water Resource Management (CWRM) has taken actions to amend the Interim Instream Flow Standards (IIFS) for several of the streams that provide water to the Kamole WTP. In September, 2008 the CWRM amended the IIFS for several of the eight streams in the five hydrologic units initially considered:[53]

- Honopou Stream
- Hanehoi / Puolua Streams
- Pinaau / Palauhulu Streams
- Waiokamilo / Kualani Streams
- Wailuanui Stream

Further actions by the CWRM are expected to consider amendment of the IIFS for nineteen additional East Maui streams that aree currently diverted into the Koolau/Wailoa system:

- Alo Stream
- Haipuaena Stream
- Hanawi Stream
- Honomanu Stream
- Kapaula Stream
- Kolea and Punalau Streams
- Kopiliula Stream
- Makapipi Stream
- Nuailua Stream
- Puakaa Stream
- Puohokamoa Stream
- Wahinepee Stream
- Waiaaka Stream
- Waianu Stream
- Waikamoi Stream
- Waikani Stream
- Wailuaiki (East) Stream
- Wailuaiki (West) Stream
- Waiohue Stream

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53. Each hydrologic unit may include several streams. Each stream listed may also include several seperately named tributary streams.

The amended IIFS established in September 2008 specify minimum stream flows measured at specific locations that must be maintained prior to any upstream diversions of water to the ditch systems. The IIFS require base flows to be maintained in the streams prior to any diversions. The existing diversion structures are not designed to provide this diversion protocol. Existing diversion structures are designed primarily to divert base stream flows to the ditch system and allow water to remain in the streams only when steam flows exceed the capacity of the ditch and diversion structures. In some cases existing sluice gates allow bypass of the diversion structures to allow water to remain in the streams. In some cases diversion structures will have to be physically reconstructed to meet the amended IIFS protocols.

The impacts of amended IIFS on the Wailoa ditch flows to the Kamole Weir are not currently possible to quantify accurately.

- First, amended IIFS have been established considering only eight of the 27 streams that are being considered. It is expected but uncertain that amendments will be made to some of the IIFS for the remaining 19 streams currently under consideration.
- Second, it is difficult to determine how much water will be required to remain in the streams that otherwise has historically been diverted even where amended IIFS have been established. The impacts of some of the amended IIFS that are specified directly below the Wailoa/Koolau ditch system diversion structures are possible to use as rough minimum estimates of decreases in diverted water flows. Amended IIFS specified further downstream of the diversion structures, however, may require releases of water in excess of or less than the amended IIFS due to the effects of "losing" or "gaining" reaches of streambed between the diversion structure and the IIFS specification location.
- Third, the CWRM has adopted and adaptive management approach to regulating stream flows and may adjust the IIFS as results of the IIFS amendments are studied and additional information becomes available.

The following amended IIFS established in September 2008 were specified directly below the Koolau Ditch:

- Piinaau Stream - 3.56 MGD
- Waiokamilo Stream - 3.17 MGD
- Wailuanui Steam - 1.97 MGD

These amended IIFS, totalling 8.7 MGD, provide a rough minimum estimate of base water flow that must be maintained in these streams that otherwise has historically been diverted into the Wailoa/Koolau Ditch system. Several amended IIFS established further downstream on three of the initial eight streams could require additional "releases" at the Wailoa/Koolau Ditch system diversion structures but the potential additional amounts, if any, are not possible to estimate at this time.

For purposes of analysis of the impacts of amended IIFS on the reliable yield of the Kamole WTP, potential reductions in Wailoa Ditch flows resulting from existing and future amended IIFS were estimated for three scenarios: 20 MGD, 30 MGD and 50 MGD reduction of base flow.

Kamole WTP System Drought Period Reliable Capacity

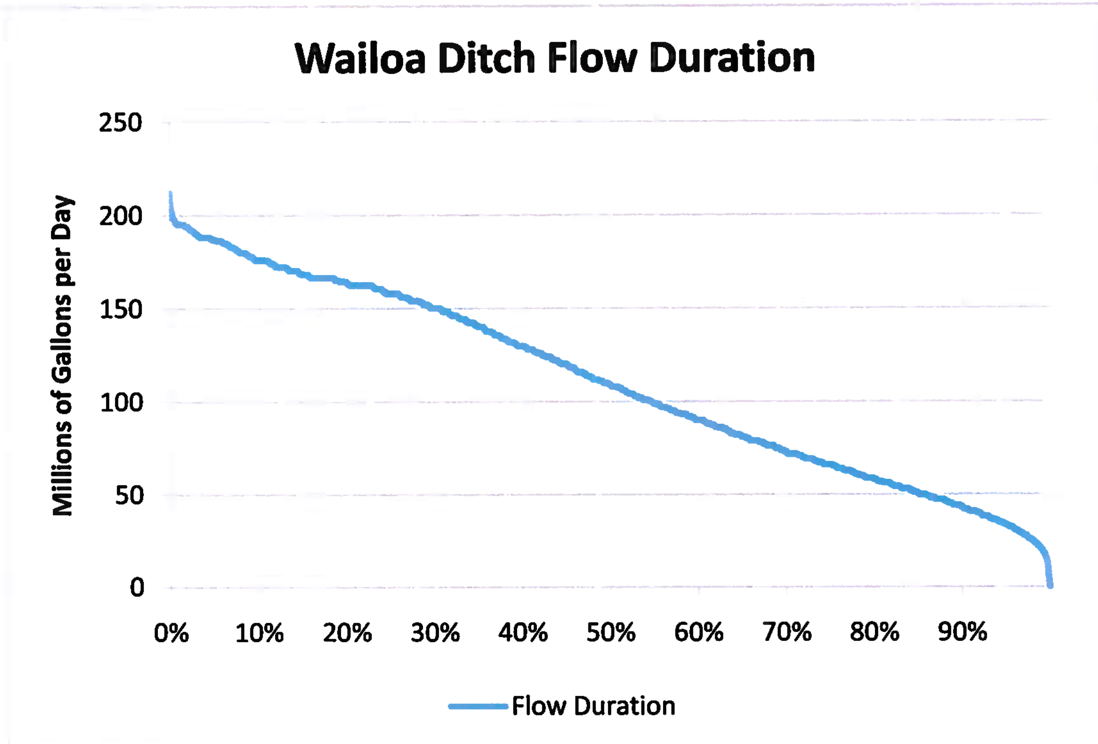
Drought period reliable capacity is a parameter used to characterize the capability of a surface water source, reservoir and WTP system to maintain continuous potable water output throughout dry months and drought periods. This parameter is used in the WUDP system and economic analyses to determine the amount of system resources that must be maintained for each year of the analyses in order to provide a uniform, sufficient level of potable water service reliability. Based on historical experience and the current implementation of allotments of water at Kamole Weir, the drought period reliable capacity of the Kamole WTP is estimated to be 4.5 MGD. Changes to the base flow characteristics of the Wailoa Ditch which supplies source water to the Kamole WTP would affect the drought period reliable capacity.

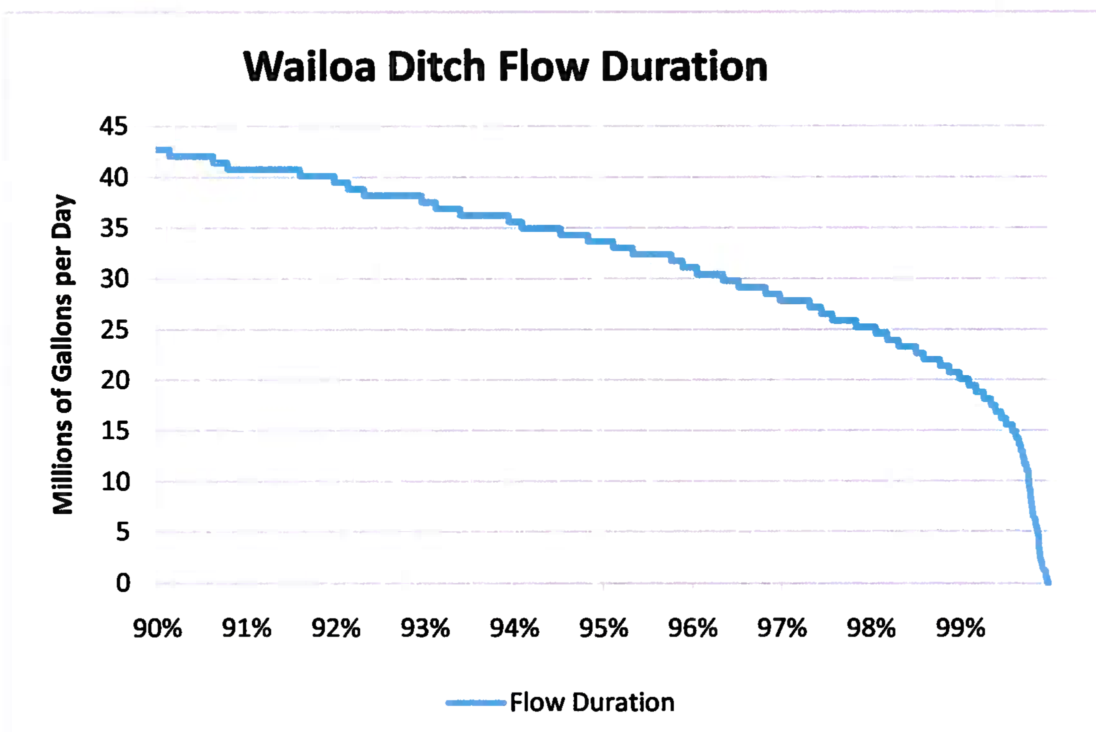
The Kamole WTP currently draws water directly from the Wailoa Ditch without any raw water reservoir storage. The reliable potable water production capacity in dry months or drought periods is limited by (1) the amount of water in the Wailoa Ditch, (2) implementation of contractual terms of a Memorandum of Understanding (MOU), dated April 13, 2000, between the County of Maui and A&B and (3) by the physical characteristics of the WTP intake structure.

According to the MOU, the DWS is allotted to up to 12 MGD of water from the Wailoa Ditch with an option for an additional 4 MGD. During low flow periods when ditch flows are greater than 16.4 MGD the DWS is allotted 8.2 MGD. When flows drop below 16.4 MGD the allotment is a 50% split between the DWS and A&B. In recent periods of low ditch flow A&B has been permissive and has not restricted the allotment of water to the DWS according to the terms of the agreement. In low flow conditions DWS withdrawals have been limited only by the amount of water available in the ditch and the physical limitations of the existing WTP intake structures.

Daily flow measurements have been recorded and are available for the Wailoa Ditch at Honopou for the period 1922 to 1987. Based on these measurements, a flow duration curve was compiled which is depicted below. This curve shows the amount of flow exceeded in the Wailoa Ditch for a range of percentages of time. Two curves are presented below showing (1) the full flow duration curve and (2) the amount of flow exceeded for percentages of time greater than 90%.

The flow duration information shows that, based on a long term historical record, water flows in the Wailoa Ditch exceed 40 MGD more than 90% of the time and exceed 20 MGD more than 99% of the time. Historically, the Koolau/Wailoa ditch system has provided a reliable source of water for the Kamole WTP. The forest and soil of the East Maui watershed area provides a regulating "reservoir" that provides substantial base flows in streams that contribute to the Koolau/Wailoa ditch system.


Wailoa Ditch Flow Duration
Millions of Gallons per Day
250
200
150
100
50
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
Flow Duration


Wailoa Ditch Flow Duration
Millions of Gallons per Day
45
40
35
30
25
20
15
10
5
0
90%
91%
92%
93%
94%
95%
96%
97%
98%
99%
Flow Duration

Analysis of Reservoir System Reliable Yield

The recent and anticipated amendments to the IIFS for the East Maui streams will result in decreased base flows in the Koolau/Wailoa ditch system. With base flows in the ditch system reduced, the reliability of the ditch system as a source of drought period reliable capacity is diminished. One method to mitigate this erosion of drought period reliable capacity is to provide raw water storage reservoir capacity to provide a reliable system yield in drought periods.

A series of analyses was performed to determine the drought period reliable yield of the Kamole WTP system assuming various sizes of raw water storage reservoirs and considering alternate assumptions regarding the allotment of Wailoa Ditch water to the WTP, the assumed storage reservoir and to A&B for irrigation. A mass flow model was developed which examines daily ditch flows for a 23,680 day period of record from 1923 to 1987. The model takes several factors into account to determine the drought period reliable capacity of the Kamole WTP:

- Wailoa Ditch Flows at Honopou
- Ditch Base Flow Reductions From Various Assumptions Re: Amended IIFS Impacts
- Losses and Gains in Ditch Flow Between Honopou and Kamole Weir (assumed in the analyses presented here to balance to zero)
- Water Withdrawn From Wailoa Ditch To Serve the Kamole WTP
- Minimum Flows Above DWS Ditch Withdrawals Used By A&B Prior To Reservoir Fill
- Limits To Amounts of Daily Diversions to Fill Reservoir
- Reservoir Evaporation and Seepage Losses
- Rainfall Contribution to Reservoir

Based on these data and assumptions, the following reliability statistics are calculated for the 23,680 day analysis period to indicate the amount of time that water is not available to the Kamole WTP at the assumed level of drought period water production:

- Number of days that water is not sufficient
- Percent of time that water is not sufficient
- Maximum number of consecutive days that water is not sufficient

The reliable yield of the Kamole WTP is determined for each set of assumed conditions such that both of the following criteria are met:

- The percentage of time in the period of record that water is not sufficient is less than 0.50% (equal to 1.8 days per year)
- The maximum consecutive number of days that water is not sufficient is less than or equal to 30.

These criteria characterize a level of drought period reliability slightly less than the recent existing reliability of the Kamole WTP at 4.5 MGD drought period yield.[54]

Several charts below depict the results of the mass flow analysis used to determine the drought period reliable capacity of the Kamole WTP.[55]

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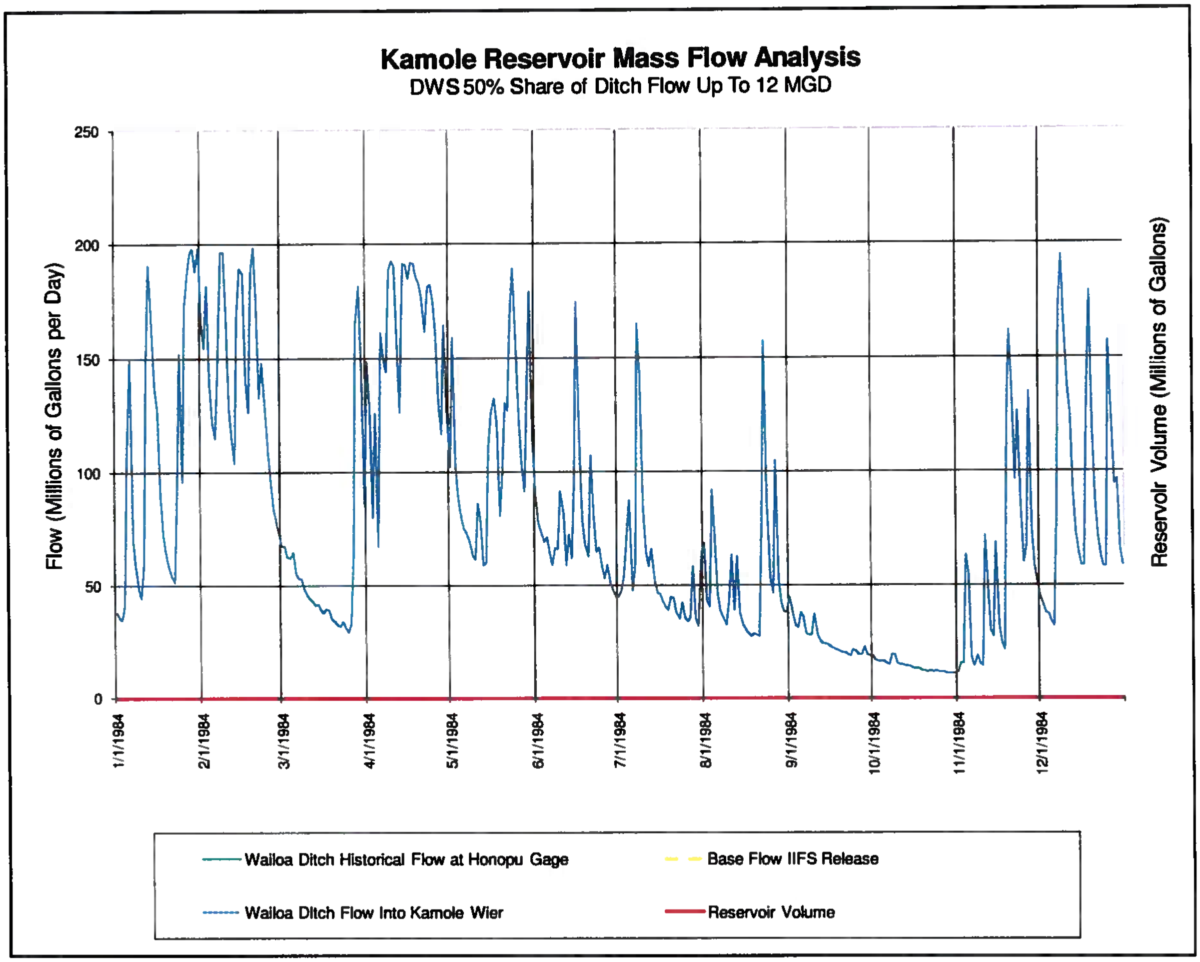
54. Raw water requirements of 5 MGD are presummed in order to provide 4.5 MGD of potable water capacity.

55. For purposes of the analyses in this appendix, non-potable water supplied to the Kula Agricultural Park during periods of low Wailoa Ditch flows is presummed to be provided by alternative means, such the recent practice of pumping water from the existing DWS Hamakuapoko wells to the Hamakua Ditch (downstream of Kamole Weir).



Analysis Assumptions	MGD
Base Flow IIFS Release Impact	0.00
Wailoa Ditch Losses (Honopou to Kamole)	0.00
DWS Base Diversion To WTP	5.00
HC&S Base Agricultural Use	100.00
Reservoir Capacity (MG)	0.00
DWS Resv. Yield to WTP (Above Base)	0.00
Total DWS Target Use (Base + Yield)	**5.00**

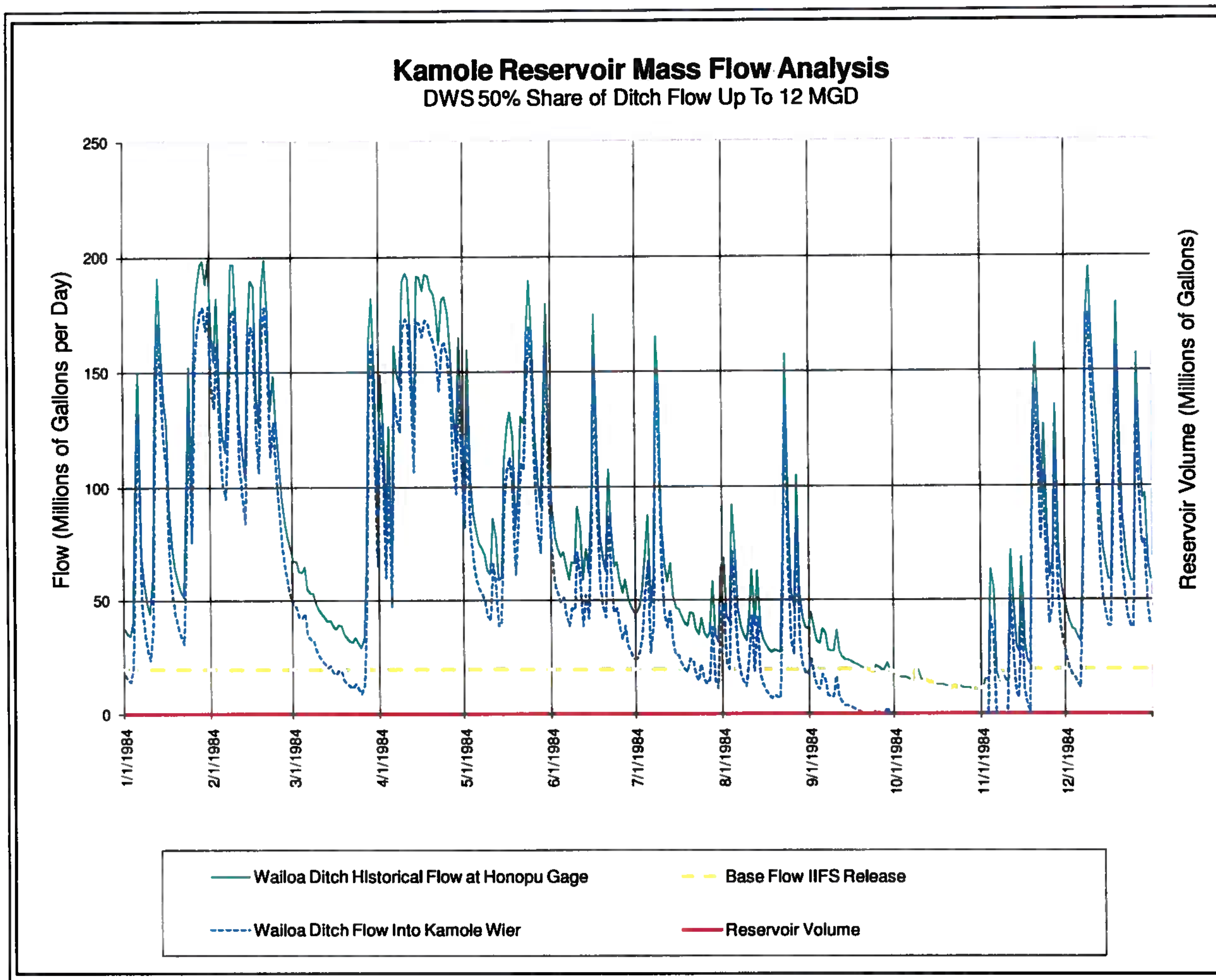
Deficiency Statistics	Period of Record 1922 - 1987 With No Reservoir DWS Base Diversion Deficient	With Reservoir DWS Base + Yield Deficient
Total Days In 23,680 Day Record	54.00	54.00
Percentage Days Deficient	0.23%	0.23%
Consequtive Days Deficient	16.00	16.00

FIGURE 1 Wailoa Ditch Historical Flows Measured at Honopou CY1984 With Water Deficiency Statistics For Kamole WTP At 5.0 MGD Drought Period Withdrawal From Ditch Assuming DWS 50% Allotment of Water At Low Flow Conditions Up to 12 MGD Ditch Flow With No Reservoir Capacity

The chart above shows daily Wailoa Ditch flows measured at Honopou for the calendar year 1984. The year 1984 is depicted in this chart and several charts below because it includes an extended dry period that is the determining criteria drought period in several of the assumed scenarios.

Although only the 1985 period is shown graphically, the deficiency statistics shown in the table below the chart are based on the entire 1922 to 1987 period of record (23,680 days). This analysis presumes that during low water flow conditions 50% of the water is allotted to the DWS and 50% to A&B in accordance with the existing April, 2000 Memorandum of Understanding.

For the period of record, assuming a daily drought period withdrawal of 5.0 MGD from the Wailoa Ditch for the Kamole WTP, there is deficient water on 54 days (equal to 0.23% of the time) with a maximum of 16 consecutive days of deficiency.



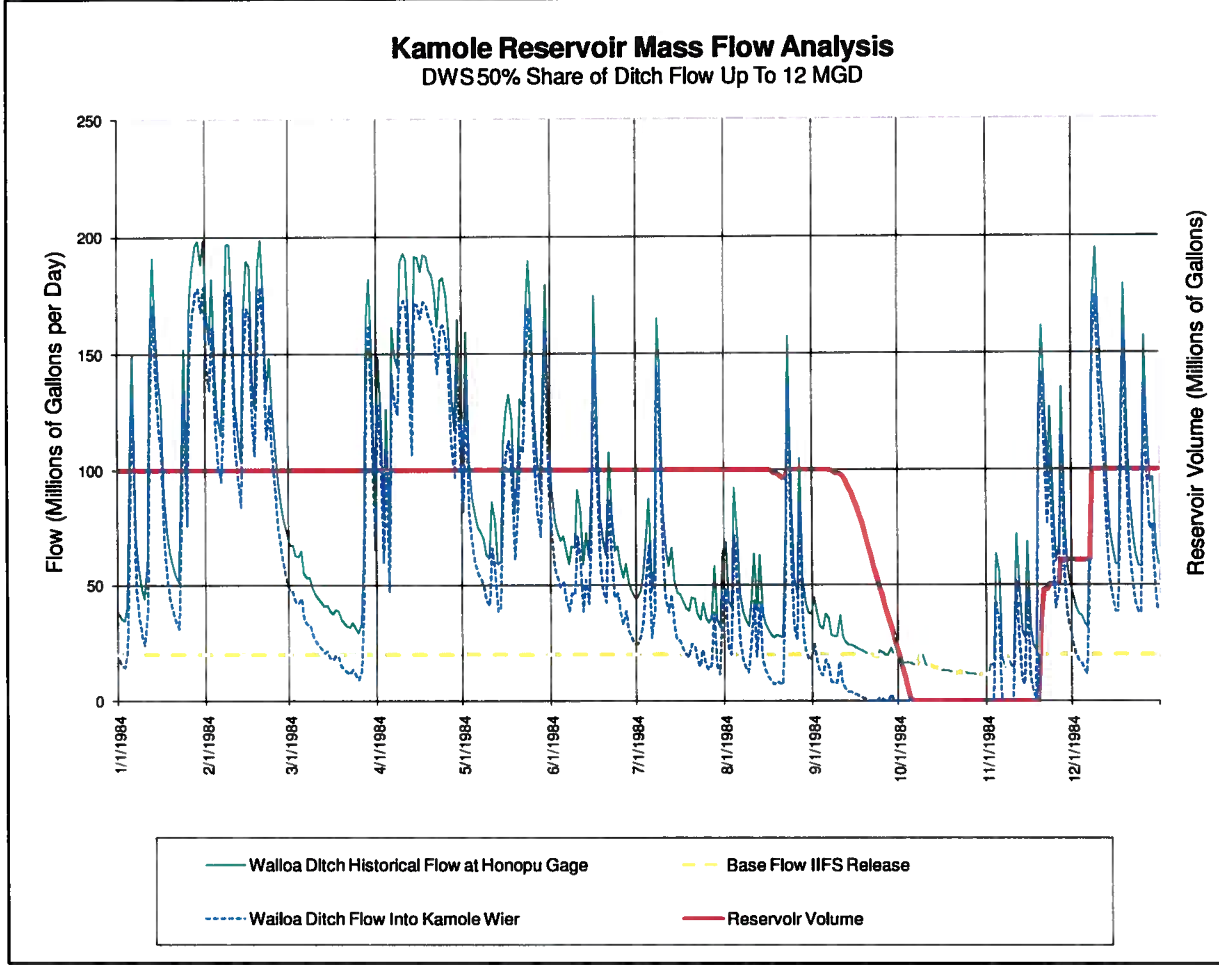
Analysis Assumptions	MGD
Base Flow IIFS Release Impact	20.00
Wailoa Ditch Losses (Honopou to Kamole)	0.00
DWS Base Diversion To WTP	5.00
HC&S Base Agricultural Use	100.00
Reservoir Capacity (MG)	0.00
DWS Resv. Yield to WTP (Above Base)	0.00
Total DWS Target Use (Base + Yield)	**5.00**

Deficiency Statistics	With No Reservoir DWS Base Diversion Deficient	With Reservoir DWS Base + Yield Deficient
Period of Record 1922 - 1987		
Total Days In 23,680 Day Record	863.00	863.00
Percentage Days Deficient	3.64%	3.64%
Consequtive Days Deficient	54.00	54.00

FIGURE 2 Wailoa Ditch Flows Showing 20 MGD Reduction in Base Flow, CY1984, With Water Deficiency Statistics For Kamole WTP At 5.0 MGD Drought Period Withdrawal From Ditch Assuming DWS 50% Allotment of Water At Low Flow Conditions Up to 12 MGD Ditch Flow With No Reservoir Capacity

The chart above shows a 20 MGD reduction in the base flow of the Wailoa Ditch that could result from amended IIFS. (As discussed above, note that there is not a direct correspondence between the amounts of IIFS amendments and the amount of reductions in ditch base flow.)

With a 20 MGD reduction in base flow and assuming a daily drought period withdrawal of 5.0 MGD from the Wailoa Ditch for the Kamole WTP, there is deficient water on 863 days (equal to 3.64% of the time) with a maximum of 54 consecutive days of deficiency. With 20 MGD reduction in Wailoa Ditch base flow there would not be sufficient water to provide reliable drought period capacity from the Kamole WTP without some mitigating actions (discussed below).



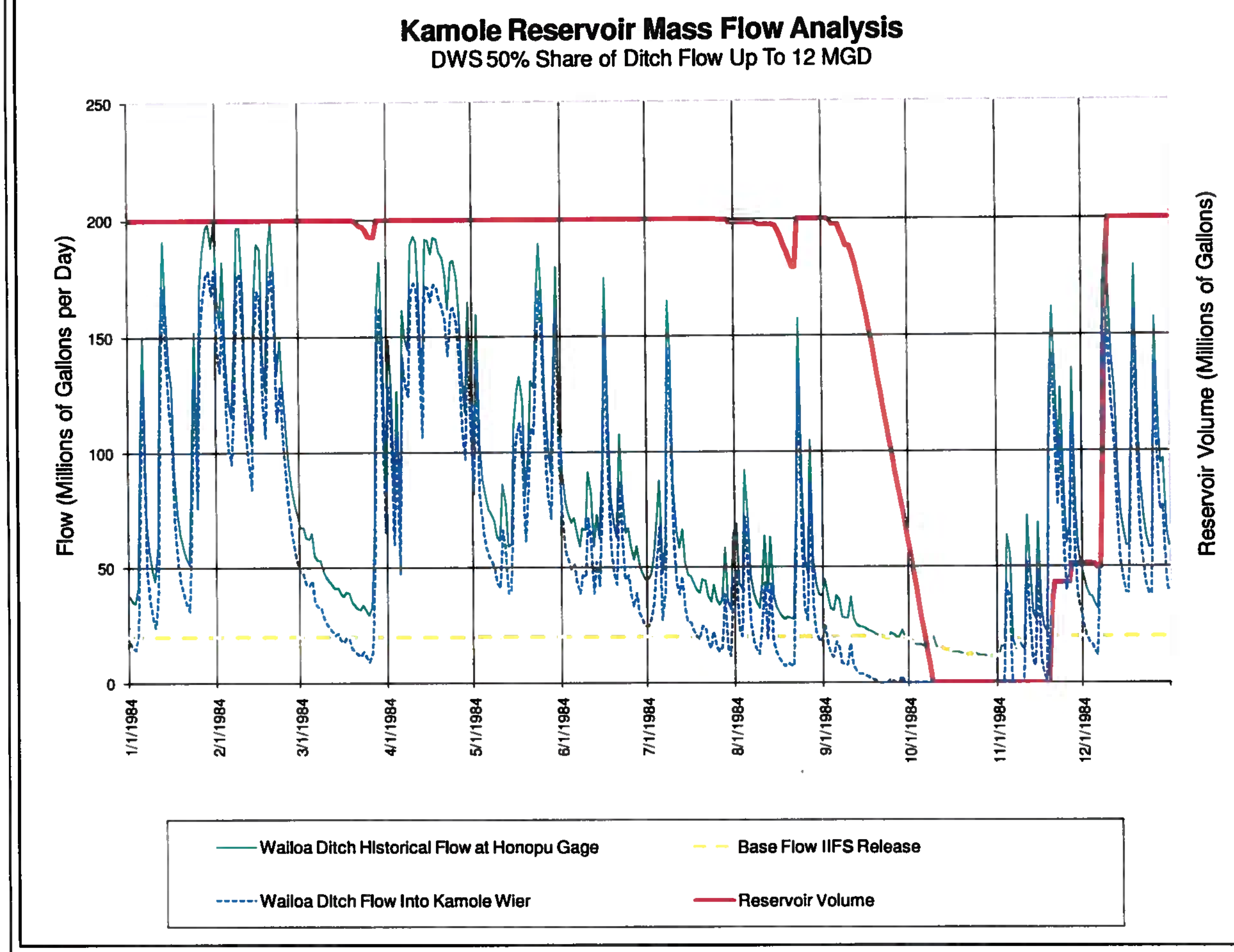
Analysis Assumptions	MGD
Base Flow IIFS Release Impact	20.00
Wailoa Ditch Losses (Honopou to Kamole)	0.00
DWS Base Diversion To WTP	4.60
HC&S Base Agricultural Use	100.00
Reservoir Capacity (MG)	100.00
DWS Resv. Yield to WTP (Above Base)	0.00
Total DWS Target Use (Base + Yield)	**4.60**

Deficiency Statistics	Period of Record 1922 - 1987 With No Reservoir DWS Base Diversion Deficient	With Reservoir DWS Base + Yield Deficient
Total Days In 23,680 Day Record	822.00	117.00
Percentage Days Deficient	3.47%	0.49%
Consequtive Days Deficient	54.00	29.00

FIGURE 3 Wailoa Ditch Flows Showing 20 MGD Reduction in Base Flow, CY1984, With Water Deficiency Statistics For Kamole WTP At 4.6 MGD Drought Period Withdrawal Assuming DWS 50% Allotment of Water At Low Flow Conditions Up to 12 MGD Flow With 100 MG Reservoir Capacity With No Contribution To Reservoir Unless Ditch Flows Exceed DWS Draw Plus 100 MGD HC&S Use.

The chart above shows a 20 MGD reduction in Wailoa Ditch base flow with a 100 million gallon raw water storage reservoir. It is assumed that, in low water flow conditions, the DWS has an allotment of 50% of the ditch flow for use in the Kamole WTP but would not withdraw any water to fill the storage reservoir water unless flow in the ditch exceed the DWS withdrawal plus 100 MGD used by A&B for irrigation purposes.[56] When ditch flows would not otherwise allow full drought period use of the Kamole WTP, reservoir water would be drawn to provide reliable supply.

56. This assumption is consistent with an earlier study prepared for the DWS regarding construction of a raw water storage reservoir for the Kamole WTP by Mink & Yuen in 1998.



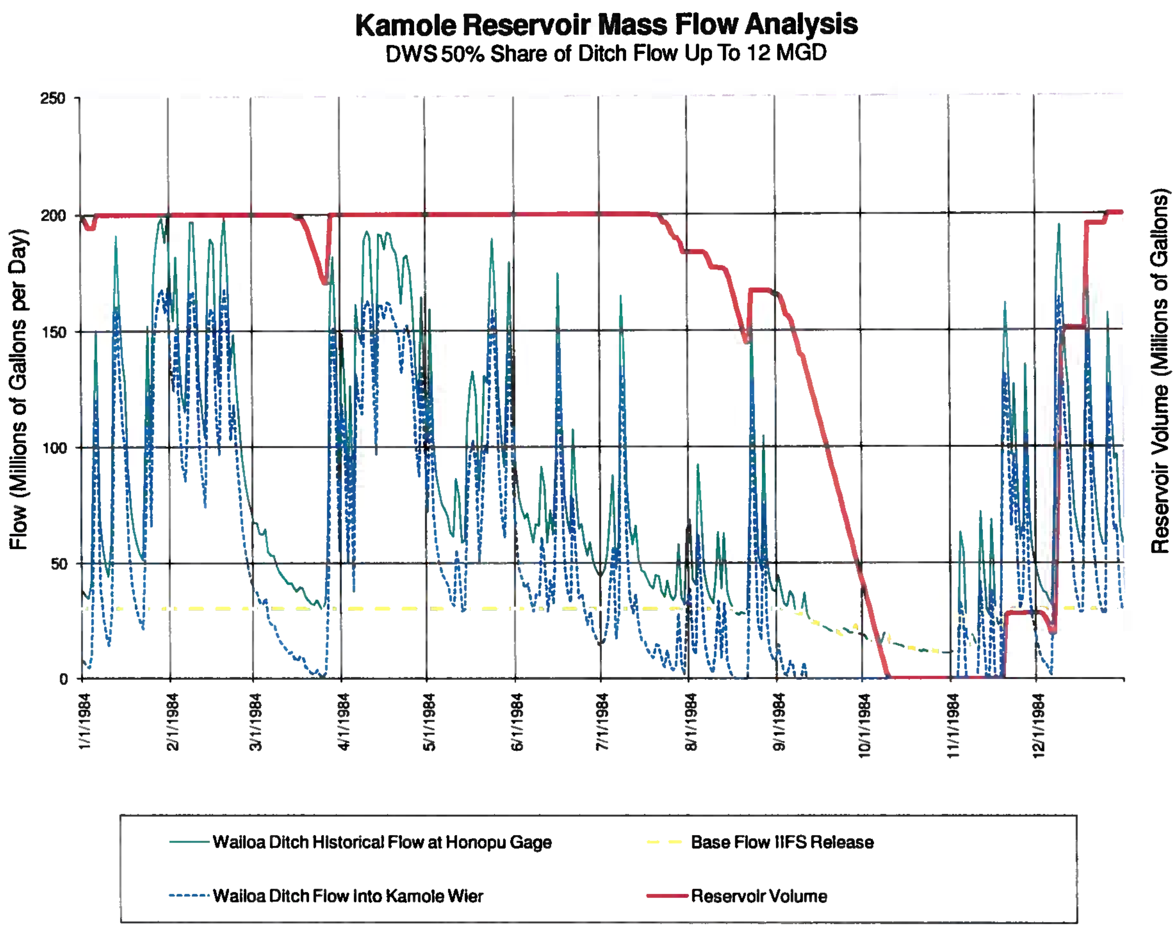
Analysis Assumptions	MGD
Base Flow IIFS Release Impact	20.00
Wailoa Ditch Losses (Honopou to Kamole)	0.00
DWS Base Diversion To WTP	7.10
HC&S Base Agricultural Use	100.00
Reservoir Capacity (MG)	200.00
DWS Resv. Yield to WTP (Above Base)	0.00
Total DWS Target Use (Base + Yield)	7.10

Deficiency Statistics	Period of Record 1922 - 1987 With No Reservoir DWS Base Diversion Deficient	With Reservoir DWS Base + Yield Deficient
Total Days In 23,680 Day Record	1222.00	115.00
Percentage Days Deficient	5.16%	0.49%
Consequtive Days Deficient	54.00	25.00

FIGURE 4 Wailoa Ditch Flows Showing 20 MGD Reduction in Base Flow, CY1984, With Water Deficiency Statistics For Kamole WTP At 7.1 MGD Drought Period Withdrawal Assuming DWS 50% Allotment of Water At Low Flow Conditions Up to 12 MGD Flow With 200 MG Reservoir Capacity With No Contribution To Reservoir Unless Ditch Flows Exceed DWS Draw Plus 100 MGD HC&S Use.

With a 20 MGD reduction in Wailoa Ditch base flow and a 100 MG raw water storage reservoir the drought period reliable yield of the Kamole WTP would be 4.6 MGD, approximately equal to the existing WTP reliable yield without reductions in ditch base flows.

The chart above shows the same assumptions as the previous chart except that a 200 MG raw water storage reservoir is assumed. With a 200 MG reservoir the drought period reliable yield of the Kamole WTP increases to 7.1 MGD. This is an increase of 2.4 MGD compared to a 100 MGD reservoir.

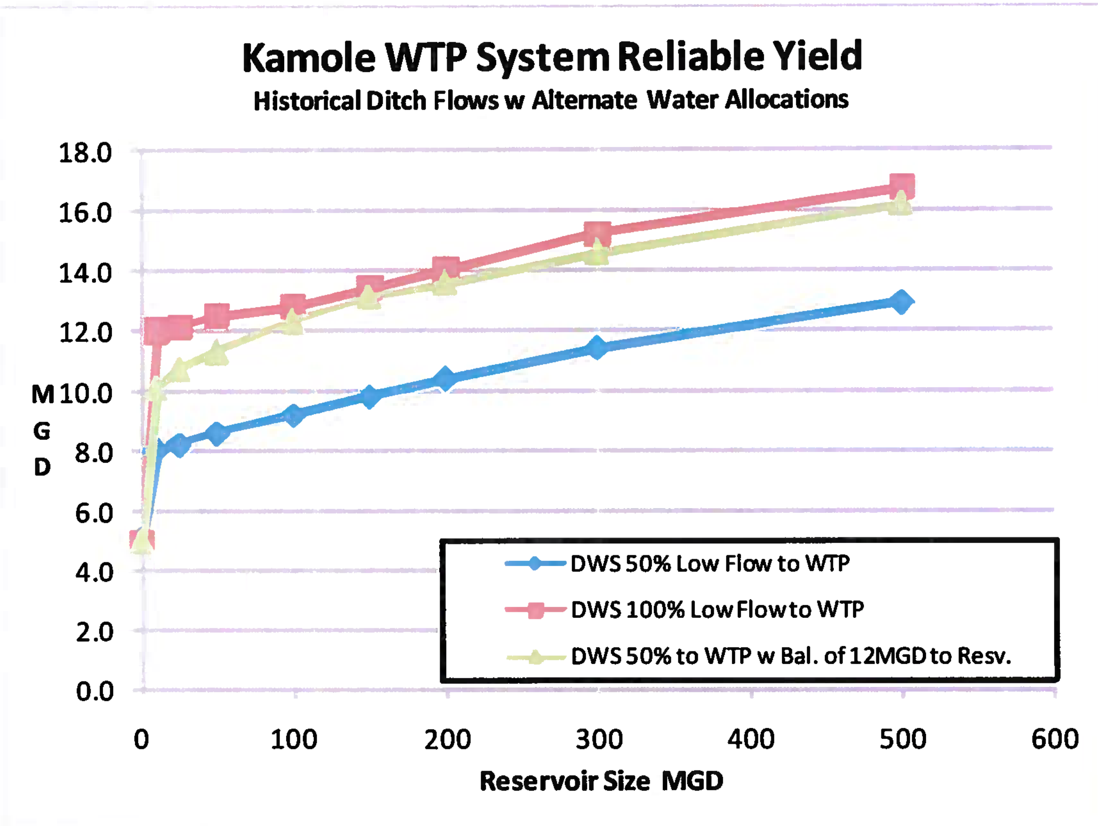


Analysis Assumptions	MGD
Base Flow IIFS Release Impact	30.00
Wailoa Ditch Losses (Honopou to Kamole)	0.00
DWS Base Diversion To WTP	4.70
HC&S Base Agricultural Use	100.00
Reservoir Capacity (MG)	200.00
DWS Resv. Yield to WTP (Above Base)	0.00
Total DWS Target Use (Base + Yield)	**4.70**

Deficiency Statistics	Period of Record 1922 - 1987 With No Reservoir DWS Base Diversion Deficient	With Reservoir DWS Base + Yield Deficient
Total Days In 23,680 Day Record	1858.00	117.00
Percentage Days Deficient	7.85%	0.49%
Consequtive Days Deficient	63.00	25.00

FIGURE 5 Wailoa Ditch Flows Showing 30 MGD Reduction in Base Flow, CY1984, With Water Deficiency Statistics For Kamole WTP At 4.7 MGD Drought Period Withdrawal Assuming DWS 50% Allotment of Water At Low Flow Conditions Up to 12 MGD Flow With 200 MG Reservoir Capacity With No Contribution To Reservoir Unless Ditch Flows Exceed DWS Draw Plus 100 MGD HC&S Use.

The chart above shows a 30 MGD reduction in base flow of the Wailoa Ditch and assumes the construction of a 200 MG raw water storage reservoir. The drought period reliable yield of the Kamole WTP with this larger amount of reduction in Wailoa Ditch base flow is 4.7 MGD, approximately equal to the reliable yield of the Kamole WTP under existing conditions assuming historical ditch flows.



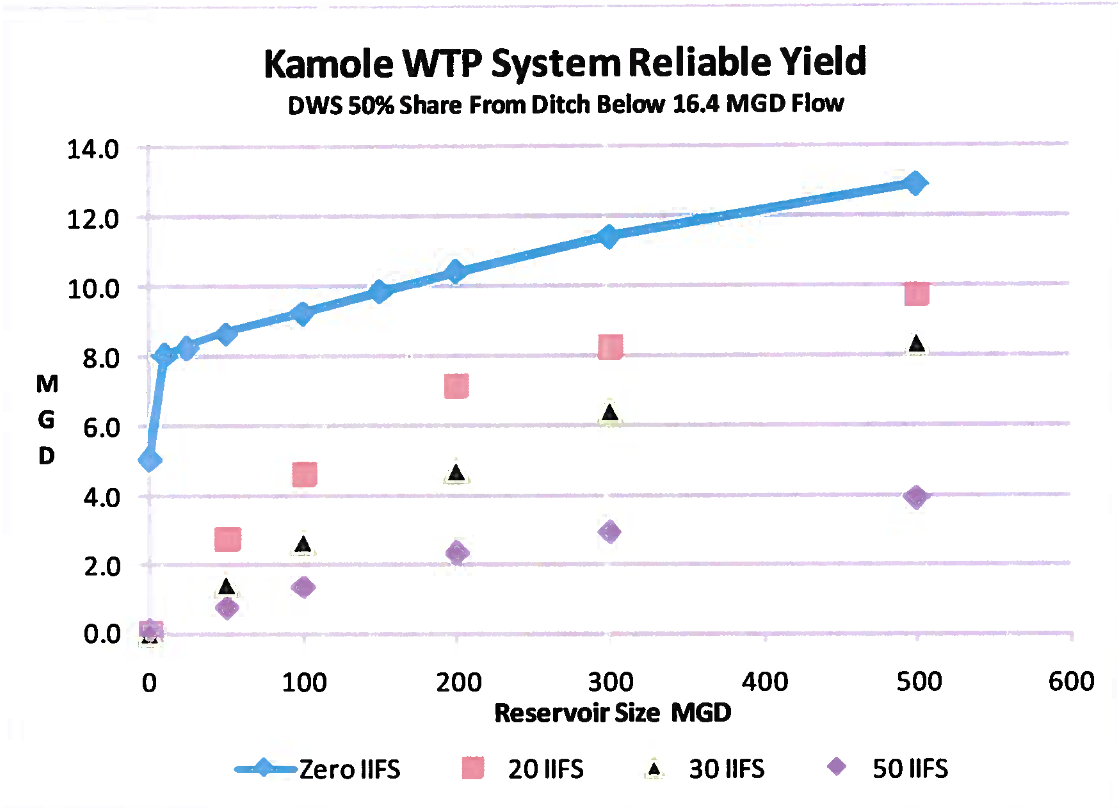
Any reservoir configuration to supply the Kamole WTP would be subject to negotiation and agreement with A&B regarding allotments of water under various ditch flow conditions. Several alternate water allotment protocols are possible. The existing MOU provides for a 50%/50% split of water when Wailoa Ditch flows at Kamole Weir are less than 16.4 MGD. A&B has been permissive, however, and has not restricted the DWS from using more than the existing allotment under low flow conditions.

Installation of a raw water storage reservoir would also require netotiation of protocols to determine what conditions and limitations would apply to withdrawing water from Wailoa Ditch to fill the reservoir. In the analyses depicted in the charts on previous pages it is presumed (strictly as an expository assumption) that water would be allowed to flow into a storage reservoir only when ditch flows were high enough to allow a minimum 100 MGD of water use by A&B beyond the presumed Kamole WTP drought period water use.

Two additional water allotment protocols are depicted in the analysis shown in the chart above. This chart shows the Kamole WTP drought period reliable yield assuming a range of raw water storage reservoir sizes under three water allotment scenarios:

- 50% allotment to DWS under low flow conditions (as assumed in charts on previous pages)
- 100% allotment to DWS under low flow conditions
- 50% allotment to DWS under low flow conditions but also allowing any balance up to 12 MGD to be used to fill the storage reservoir when water is available (before 100 MGD minimum allottment is counted).

Note that, with even the smallest size reservoir, the reliable yield of the Kamole WTP jumps substantially. This is because it is presumed that with the installation of any reservoir the existing



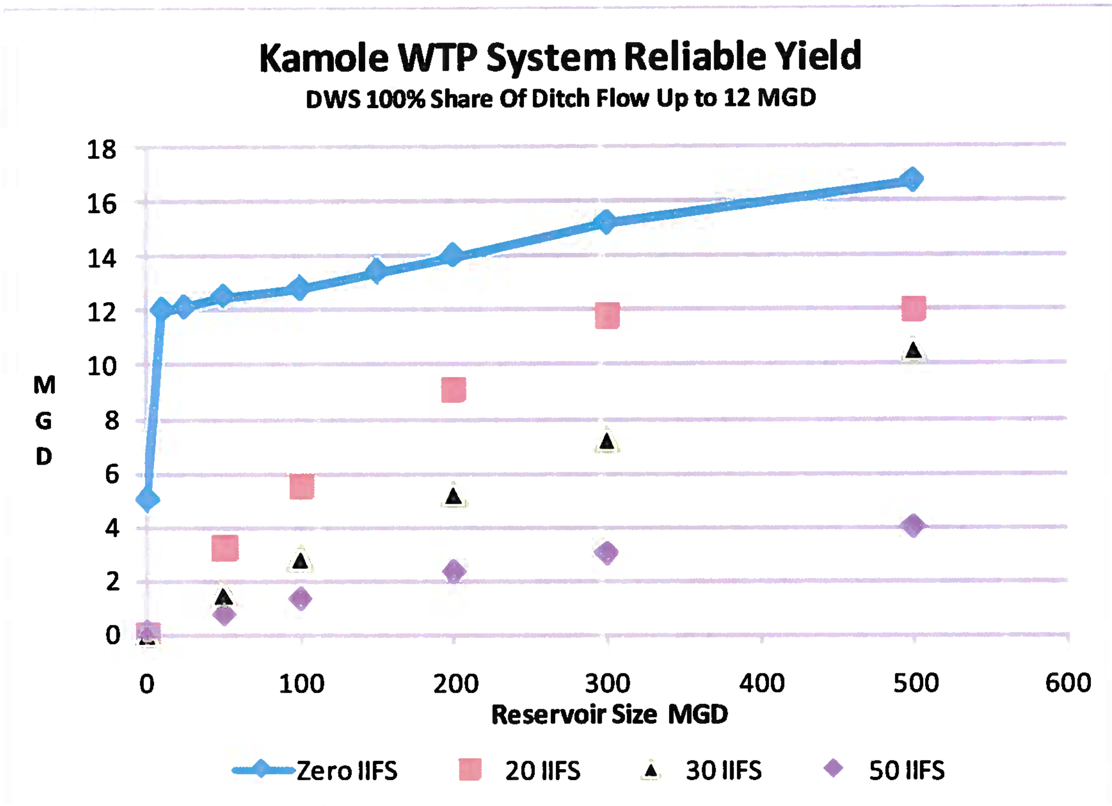
constraints due to limitations caused by the the WTP intake structure would be mitigated and the reliable yield would increase to the limits that are due to ditch flows and contractual allotments.

The increases in drought period reliable yield are hypothetical, however, since amendments to the IIFS on the tributary East Maui streams will have impacts as shown in the charts below.

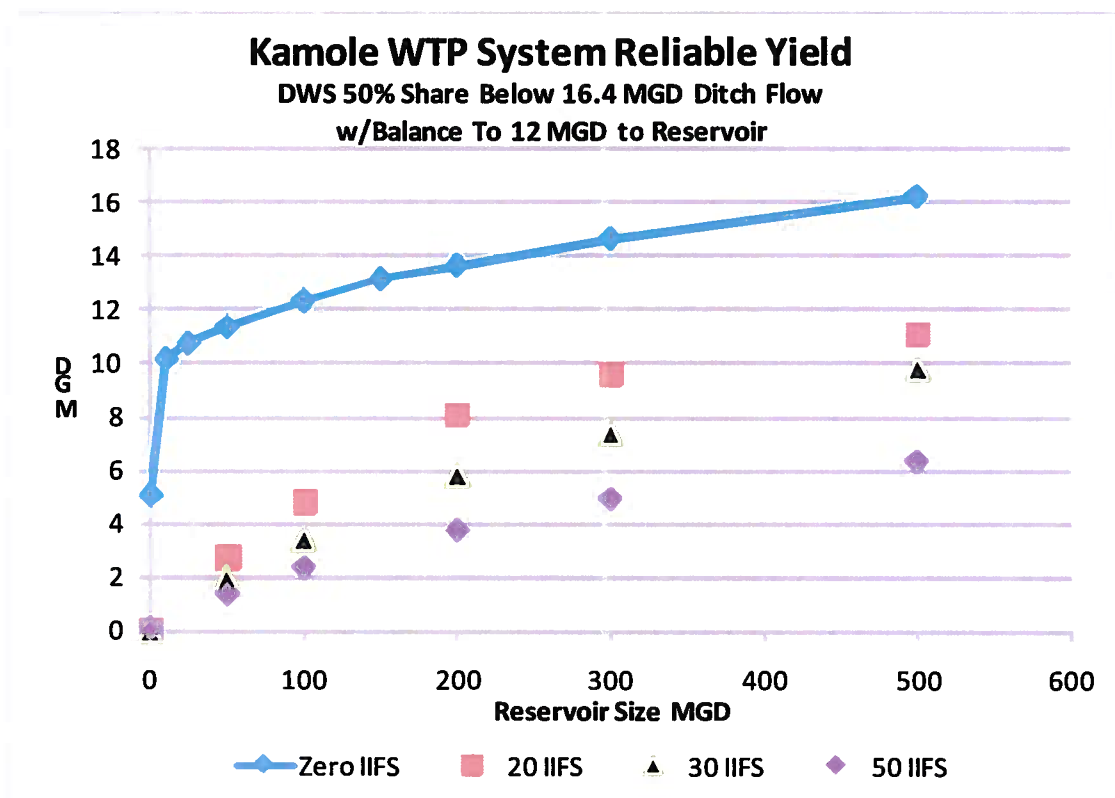
The chart above shows the Kamole WTP drought period reliable yield under several assumptions regarding reductions in Wailoa Ditch base flows and various raw water storage reservoir sizes. All of these results assume a 50% allotment of water to the DWS under low ditch flow conditions consistent with the existing MOU and no allotment of water to fill a storage reservoir until ditch flows exceed 100 MGD above the DWS Kamole WTP daily withdrawals.

The results of the detailed charts previously shown in Figures 3, 4 and 5 above are shown on this chart as points for a 100 MG reservoir and 200 MG reservoir with 20 MGD base flow reductions (Figures 3 and 4) and for a 200 MG reservoir with 30 MGD base flow reduction (Figure 5). An extended range of results of additional analyses is shown.

The charts below show the results of similar analyses assuming a 100% allotment of water to the DWS under low ditch flow conditions and a 50% allotment to DWS under low flow conditions with the balance of available ditch flow up to 12 MGD allowed to flow into the storage reservoir under low flow conditions.



Kamole WTP System Reliable Yield
DWS 100% Share Of Ditch Flow Up to 12 MGD
18
16
14
12
10
8
6
4
2
0
MGD
0
100
200
300
400
500
600
Reservoir Size MGD
Zero IIFS
20 IIFS
30 IIFS
50 IIFS



Kamole WTP System Reliable Yield
DWS 50% Share Below 16.4 MGD Ditch Flow
w/Balance To 12 MGD to Reservoir
18
16
14
12
10
8
6
4
2
0
MGD
0
100
200
300
400
500
600
Reservoir Size MGD
Zero IIFS
20 IIFS
30 IIFS
50 IIFS

CONCLUSION

The charts above show that reductions in Wailoa Ditch base flows substantially reduce the drought period reliable yield of the Kamole WTP. Regardless of several alternate assumptions regarding allotment of water under low flow conditions, a raw water storage reservoir would be necessary to maintain existing drought period reliable capacity under conditions of reduced base flows:

- Without raw water storage capacity, a 20 MGD reduction in Wailoa Ditch base flows would reduce the drought period reliable capacity of the Kamole WTP to zero.
- A 100 MG reservoir would approximately maintain existing Kamole WTP drought period reliable capacity assuming 20 MGD reduction in ditch base flows.
- A 200 MG reservoir would approximately maintain existing Kamole WTP drought period reliable capacity assuming a 30 MGD reduction in ditch base flows.
- With construction of a water storage reservoir and with negotiated water allotment protocols with A&B, the drought period reliable capacity of the Kamole WTP could be increased incrementally beyond existing levels.

Economic Analysis

In the examination of the candidate strategies in the Upcountry District WUDP process, the drought period reliable capacity of the Kamole WTP was assumed to be maintained at its present level of 4.5 MGD. The impacts of the amendments to the IIFS for the East Maui streams are being considered in the WUDP process in conjunction with several integrated strategies to meet Upcountry District system needs. The economics of IIFS impacts are examined below independently, presuming that these impacts will materialize regardless of any of the strategies considered to meet new system growth in the planning timeframe.

The economic impacts of reductions in Wailoa Ditch flows available to the Kamole WTP are characterized below as the costs to mitigate the reductions by any of several actions being considred:

- construction of a raw water strorage reservoir
- construction of a series of basal groundwater wells to provide an alternate source of drought period reliable capacity
- contractual arrangements with A&B/EMI regarding use of available Wailoa Ditch water or use of existing DWS or HC&S groundwater wells to supplement Hamakua Ditch flows.

In prior Upcountry WUDP analyses, several specific options were considered regarding the drought period capability of the Kamole WTP including:

- Increasing the drought period reliable capacity of the Kamole WTP by construction of a raw water storage reservoir
- Incrementally increasing the drought period reliable capacity of the Kamole WTP by improvments to remove existing WTP water intake constraints during low ditch flow conditions
- Providing basal groundwater wells as an alternative to the drought period reliable capacity provied by the Kamole WTP.

These options were considered as alternatives to increase the contribution of the Kamole WTP to meet new water demands or to provide "drought-proof" water service using only groundwater sources. The results of these analyses provide information regarding the costs to mitigate decreases in Kamole WTP reliability resulting in decreased Wailoa Ditch base flows:

- The cost of providing basal groundwater wells to replace the existing 4.5 MGD drought period reliable capacity of the Kamole WTP would be approximately $32 million (NPV $2006).
- The value (avoided costs) of providing 1, 2 or 3 MGD additional Kamole WTP drought period reliable capacity (in terms of avoiding the need for basal groundwater well development) would be approximately $8, 16 or 21 million respectively (NPV $2006).

These analyses indicate that the costs to replace each 1 MGD of reduction in Kamole WTP drought period reliable capacity using basal groundwater wells is approximately $7 to 8 million. Note that, although related, the impacts on drought period reliable capacity do not equate directly to the magnitude of the amended instream flow standards.

The costs to maintain the drought period reliable capacity of the Kamole WTP by construction of a raw water storage reservoir would depend on (1) reservoir construction costs, (2) the amount of reduction of base flow in the Wailoa Ditch resulting from amendments to the IIFS and (3) contractual arrangements between A&B regarding allotments of water from the Wailoa Ditch in low flow conditions. None of these factors are currently known with accuracy.

Costs for reservoir construction are uncertain due to a lack of recent comparable projects. Rough estimates are as follows:

- Building a 100 MG reservoir to mitigate a 20 MGD reduction in Wailoa Ditch base flow could cost about in the range of $15 to 30 million.
- Building a 200 MGD reservoir to mitigate a 30 MGD reduction in Wailoa Ditch base flow could cost in the range of $30 to $60 million.