SECTION 1

INTRODUCTION

The City of San Diego retained Brown and Caldwell to conduct a pilot test to evaluate the biological aerated filter (BAF) process as a potential means of providing space-effective secondary treatment at the Point Loma Wastewater Treatment Plant (PLWTP). Additionally, the merits of using high-rate clarifier/thickeners (HRCT) were evaluated as a potential replacement of the existing primary sedimentation basins at the plant. This report marks the culmination of the two-phase pilot study and provides the City with the results and findings of the 43-week pilot test. The report's conclusions and recommendations will assist in refining the budgetary cost estimate for converting the PLWTP to full secondary treatment and defining design criteria for the BAF facilities and the HRCT.

In this section, a background on the Metropolitan Sewerage System and existing treatment facilities is discussed. This information is followed by a description of the current secondary treatment standards modification (i.e., the 301(h) waiver) for the discharge at the PLWTP, the project driver and the project objectives.

Metropolitan Sewerage System and Existing Facilities

The City of San Diego owns and operates the Metropolitan Sewerage System (Metro System). The Metro System serves a 450-square-mile area that includes incorporated areas of the City of San Diego and the following 15 participating agencies consisting of water/sanitation districts and cities:

- City of Chula Vista
- City of Coronado
- City of Del Mar
- City of El Cajon
- City of Imperial Beach
- City of La Mesa
- City of National City
- City of Poway
- Lakeside-Alpine Sanitation District
- Lemon Grove Sanitation District
- East Otay Mesa Sewer Maintenance District
- Otay Water District
- Spring Valley Sanitation District
- Padre Dam Municipal Water District
- Wintergardens Sewer Maintenance District.

Several miles of pipelines and a myriad of pump stations collect and convey raw wastewater from the service area to one of three treatment facilities:

- North City Water Reclamation Plant (NCWRP)
- South Bay Water Reclamation Plant (SBWRP)
- Point Loma Wastewater Treatment Plant.

The NCWRP has the capacity to treat up to 30 million gallons per day (mgd) of average annual daily flow (AADF) of raw wastewater from the northern regions, mainly from the City of Del Mar, City of Poway and northern City of San Diego communities such as Mira Mesa, Rancho Peñasquitos, Scripps Ranch, and Rancho Bernardo. The NCWRP can produce tertiary treated wastewater for reuse in surrounding areas. When reclaimed water demand is low, treated water is returned to the Metro System (via the Rose Canyon Trunk Sewer) for eventual routing to the PLWTP for treatment and ocean disposal.

The SBWRP has the capacity to treat up to 15 mgd AADF of raw wastewater originating from the South Bay region of San Diego County. Treated wastewater will be for a variety of uses in the surrounding areas. Excess treated wastewater is discharged through the South Bay Ocean Outfall (SBOO), an ocean outfall shared by the City of San Diego for disposal of SBWRP effluent and the International Boundary Water Commission (IBWC) for disposal of effluent from the International Wastewater Treatment Plant.

Figure 1.1. The Point Loma Wastewater Treatment Plant Can Treat up to an Average of 240 Million Gallons Per Day.

Wastewater not treated at the NCWRP or SBWRP eventually arrives at the PLWTP for treatment and final disposal. The rated plant capacity is 240 mgd AADF and 432 mgd peak wet weather flow (PWWF). The PLWTP is located on the western side of the Point Loma Peninsula at 1902 Gatchell Road. It is on the Fort Rosecrans Military Reservation, bounded by land occupied by the United States Navy to the north, the Fort Rosecrans National Cemetery to the east, Cabrillo National Monument to the south, and the Pacific Ocean to the west.

After receiving coarse screening at Pump Station No. 2, the wastewater arriving at the PLWTP is fine-screened and degritted before coagulants and flocculants are added to remove up to 58 percent of the incoming 5-day total biochemical oxygen demand ($TBOD_5$) and more than 85 percent of the incoming total suspended solids (TSS) in 12 primary sedimentation basins. The chemically enhanced primary treated (CEPT) wastewater is discharged to the Pacific Ocean by gravity through the 4.5-mile Point Loma Ocean Outfall (PLOO).

Solids removed at the PLWTP are digested onsite in eight anaerobic digesters before being pumped 17 miles to the Metropolitan Biosolids Center (MBC). Solids from the SBWRP are returned to the Metro System, commingling with the raw wastewater and eventually removed at the PLWTP. Raw and biological solids from the NCWRP are conveyed to the MBC for thickening and anaerobic digestion. The NCWRP digested sludge is mixed with the PLWTP sludge for dewatering.

Processed sludge from MBC is currently trucked to an approved landfill and land application site for final disposal.

Secondary Treatment Requirement Modification

The United States Environmental Protection Agency (USEPA) and the San Diego Regional Water Quality Control Board (SDRWQCB) administer the effluent requirements for disposal to navigable waters. Locally, the SDRWQCB issues a National Pollutant Discharge Elimination System (NPDES) permit to each discharger, establishing treatment and monitoring requirements that must be met. Under the Clean Water Act of 1972, all wastewater discharged to the ocean must receive at least secondary treatment, unless modifications are made in accordance with Section 301(h) of that Act.

Secondary treatment removes most of the organic matter present in the wastewater, which has typically received preliminary and primary treatment (processes that remove floating or settleable solids from the raw wastewater). Current regulations require that the secondary-treated effluent contain no more than the concentrations of $TBOD_5$ or 5-day carbonaceous biochemical oxygen demand ($CBOD_5$), and TSS presented in Table 1.1.

Table 1.1. Typical Secondary Treatment Plant Effluent Requirements

Parameter	30-Day Average (mg/L)	7-Day Average (mg/L)
$TBOD_5$	30	45
$CBOD_5$	25	40
TSS	30	45

In addition, at least 85 percent of the TSS in the raw wastewater must also be removed, and the pH cannot fall below 6 nor exceed 9 at any time.

EPA allows delegated states to write their NPDES permits in terms of either $TBOD_5$ or $CBOD_5$. The SDRWQCB has indicated that dischargers can select to be regulated using $TBOD_5$ or $CBOD_5$. For reasons to be explained later in this report, the City will likely select requirements using $CBOD_5$.

Exemptions from secondary treatment requirements can be filed with the USEPA pursuant to Section 301(h) of the Clean Water Act. This modification is granted to dischargers only if it can be demonstrated that discharge of effluent receiving less than full secondary treatment will not degrade the quality and impact the beneficial uses of the receiving waters. Stringent monitoring activities are imposed on the discharger under such a modified permit. Only the requirements for $TBOD_5$, $CBOD_5$, TSS, and pH can be modified in such a permit; all other requirements for the discharge remain the same.

The City of San Diego was granted a waiver from secondary treatment standards on November 9, 1995, when the SDRWQCB and the USEPA jointly adopted Order No. 95-106, NPDES Permit No. CA0107409. Order No. 95-106 allowed the City to discharge effluent from Chemically Enhanced Primary Treatment (CEPT) to the Pacific Ocean and established the requirements and limitations for the discharge. The Order was subject to a 5-year review and renewal process. On September 13, 2002, the SDRWQCB and USEPA renewed the waiver, establishing the current effluent standards shown in Table 1.2.

Table 1.2. Current PLWTP Effluent Standards

Parameter	Mean Annual Percent Removal	Mean Monthly Percent Removal	Monthly Average	Annual Mass Emission[(a)]
TSS	N/A	≥ 80%	75 mg/L	15,000 mt/yr
$TBOD_5$	≥ 58%	N/A	N/A	N/A

mt/yr = metric tons per year

(a) Discharge shall not exceed an annual TSS mass emission of 15,000 mt/yr through December 31, 2005. Effective January 1, 2006, the discharge shall not exceed an annual TSS mass emission of 13,599 mt/yr.

Project Driver

The main project driver is the City's commitment to 1) have available the most cost-effective facilities in place should an increase in treatment be required; and 2) meet the TSS annual mass emission limit shown in Table 1.2. The City's Metropolitan Wastewater Plan (MWP), published in November 2003, delineates proposed facilities that will need to be constructed in order to stay below the TSS mass emission limit of 13,599 mt/yr. Using revised flow and load projections based on the San Diego Association of Governments (SANDAG) 2020 growth projections, the City developed a timeline, shown in Table 1.3, for the startup of new wastewater facilities that will reduce the amount of TSS discharged to the ocean and consequently comply with the waiver standard. The City is in the process of revising the 2003 Master Plan using SANDAG 2030 growth projection. The projection is anticipated to lower the flow rates resulting in a possible 7-year delay of the projects indicated.

Not shown in Table 1.3 are costly pipelines and pump stations that must also be constructed to convey the wastewater to the treatment facilities. Adding a secondary treatment component to the existing PLWTP can provide the needed TSS removal without having to build new conveyance facilities. This alternative is potentially less costly than the current plan. However, due to the PLWTP's somewhat remote location, the alternative must provide secondary treatment at minimal footprint.

Table 1.3. Proposed Facilities under the 2003 Metropolitan Wastewater Plan

Facility	Proposed Capacity (mgd)	Proposed Startup Year
South Bay Wastewater Treatment Plant – Phase I	21	2018
Mission Valley Wastewater Treatment Plant	15	2030
North City Water Reclamation Plant – Phase II	10	2033

Through extensive evaluation of various secondary treatment alternatives (to be described in a subsequent section), the two most widely used BAF systems (Infilco Degremont's Biofor-C and Krüger's Biostyr) and a HRCT suitable for the PLWTP application (Infilco Degremont's Densadeg) were selected for pilot testing. The systems can provide the necessary treatment at a reduced footprint.

Three alternative configurations are envisioned for incorporating the BAF into the process at the PLWTP:

- Alternative 1 – Use BAF to treat CEPT effluent to secondary level. Recycle backwash to the primary sedimentation basin (PSB) influent channel to co-settle with primary sludge. Pump co-settled sludge to sludge holding tank for subsequent thickening and anaerobic digestion.

- Alternative 2 – Use BAF to treat CEPT effluent to secondary level. Thicken backwash in a HRCT. Recycle the HRCT effluent to the PSB influent channel. Pump thickened solids to the sludge holding tank for subsequent anaerobic digestion.

- Alternative 3 – Replace existing PSBs with HRCTs. Use BAF to treat CEPT effluent from the HRCT. Recycle backwash to the HRCT influent and co-settle BAF backwash solids with primary sludge. Pump thickened solids to the sludge holding tank for subsequent anaerobic digestion.

  The pilot test was developed to evaluate Alternatives 1 and 3. Because insufficient backwash solids are generated by the BAF pilot units, evaluating the use of the HRCT to thicken the backwash solids was considered infeasible. Under Phase II, however, a lab-scale dissolved air flotation thickener (DAFT) was evaluated for this purpose.

Pilot Test Elements and Objectives

Several elements collectively defined the pilot test, including the following:

- Phase I – Test performance of BAF using CEPT effluent produced at the PLWTP

- Phase II – Test performance of Densadeg (the selected HRCT) and continue testing BAF using Densadeg effluent
- Stress Testing – Test BAF and Densadeg under peak hydraulic loading
- Off-Gas Testing – Determine oxygen transfer efficiency in BAF
- Media Sampling – Sample BAF media to get an idea of biofilm characteristics
- Others Tests
    - ✓ DAFT Feasibility – Determine if DAFT can be used to thicken BAF backwash and co-thicken BAF backwash and primary sludge
    - ✓ NOD Impact – Determine the impact of nitrogen oxygen demand (NOD) on $TBOD_5$ values

A brief description of each test, along with its objectives, is provided below.

Phase I – BAF with Existing PLWTP Facilities. The Phase I pilot test was performed first, using the CEPT effluent from the existing PSB to determine each BAF unit's performance under various hydraulic, solids and organic loading rates. The Phase I pilot program was designed to meet the following objectives:

- Validate the BAF-based assumptions used to generate capital and operation and maintenance costs estimates and space requirements reported in an earlier technical memorandum ("Evaluation of Biological Aerated Filters for Point Loma Wastewater Treatment Plant," June 2003).
- Validate design parameters proposed by each BAF vendor.
- Determine the performance of the two BAF systems operated over a range of anticipated seasonal hydraulic, organic and solids loadings.
- Develop solids generation factors required to support the selection of the appropriate solids thickening scheme to obviate the need for additional anaerobic digestion capacity at the PLWTP.
- Determine the settleability of backwash solids, and their ability to co-settle and co-thicken with primary sludge.
- Determine aeration and power requirements for each BAF system.
- To determine the headloss development over the operational period.

Phase II – BAF with Densadeg. Phase II of the pilot test involved directing screened raw wastewater to a Densadeg pilot test unit. The PLWTP configuration and the need to control the ferric chloride and polymer dosage to the Densadeg precluded the use of the existing aerated grit chamber to degrit the raw wastewater. Due to concerns about the negative or positive impact of grit on the Densadeg performance, a small Eutek Teacup was brought in midway through the testing to degrit the screened raw wastewater.

Throughout the Phase II test, the BAF units were operated and monitored in the same manner as during the Phase I test period. The same objectives for the BAF listed for Phase I applied to Phase II. In addition, the following additional objectives applied:

- Determine performance under hydraulic rates proposed by the vendor
- Determine if Densadeg can achieve the same performance as existing PSBs
- Determine the impact of using Densadeg on performance of the BAF units
- Determine the impact of varying chemical dosage on Densadeg and BAF units performance
- Determine the optimum coagulant/polymer feed and sludge recycle rates.

Stress Testing. Stressing the BAF and Densadeg units to determine how they perform and the quality of effluent they produce under various high hydraulic rates was the overall goal of Stress Testing. The tests were also designed to validate the manufacturer's proposed peak loading criteria and determine if the units can perhaps operate at higher loadings. Specific goals relative to each process are described below.

The goal of the BAF stress testing was to determine the maximum hydraulic loading rate that each BAF pilot unit can operate under and still maintain an a good effluent quality. The loading rates that produced successful results can then be used when developing design criteria for the PLWTP system.

Densadeg is to be used at Point Loma only if the City cannot obtain additional land. Densadeg can be used to reduce the surface area required for chemically enhanced primary treatment. The existing PLWTP primary sedimentation basins (12 units or a total of 162,000 ft^2 of treatment area) are rated to treat a peak wet weather hourly flow of 432 mgd while meeting the current NPDES 30-day average limit for TSS of 75 mg/L. From 1996 to 2001, the maximum 30-day rolling average TSS concentration in the PLWTP effluent was 52 mg/L. If employed, it is conceivable that Densadeg will be constructed before the BAF units. Under this scenario, the Densadeg must be able to meet the current most stringent effluent standard which is currently the 30-day average limit for TSS. Since there is no instantaneous limits for the current permit, the City, Brown and Caldwell, and IDI all agreed that the goal of the Densadeg stress testing was to determine if Densadeg can effectively treat Point Loma screened wastewater at a rise rate of 12.4 gpm/ft^2 (the hydraulic loading rate proposed by IDI for a full-scale flow of 432 mgd) while consistently producing an effluent with a TSS concentration below 65 mg/L. A 10 mg/L cushion from the actual TSS limit instituted as a pilot evaluation guide.

Off-Gas Testing. Air requirement calculations are based on the theoretical oxygen demand estimates and field oxygen transfer efficiency. During the pilot test, oxygen transfer efficiency was assessed in both Biofor-C and Biostyr reactors using in situ off-gas testing conducted by Dr. Michael Stenstrom of the University of California, Los Angeles. Several conditions for each column were evaluated. The dissolved organic carbon (DOC) and chemical oxygen demand (COD) were measured at the conclusion of the test, and various observations were made.

Media Sampling. The objective of sampling the media is to get a better idea of the types of organisms that exist at various depths of the column and to determine the percentage of bacteria that is firmly attached versus those that are loosely attached or suspended. An additional purpose was to evaluate the effectiveness of backwashing, if a valid sampling procedure could be developed.

Other Tests. Other tests were conducted not directly related to BAF performance, but more focused towards understanding the impacts associated with the liquid and solids effluent from the BAF.

DAFT Feasibility. In dissolved-air flotation (DAF) systems, air is initially dissolved in the incoming stream while under pressure. The air-saturated stream is then released in a tank open to the atmosphere. This reduction in pressure causes the dissolved air to come out of solution, producing fine bubbles much like when a bottle of soda pop is opened for the first time. The fine bubbles attach to particles in the incoming stream, raising them to the surface. Particles that have a higher density than the liquid are also raised because the air-particle agglomerates are lighter than the surrounding liquid. Once the particles have been floated to the surface, thickening takes place by means of drainage of water. Thickened solids can then be collected by a skimming operation. The principal advantage of flotation over gravity thickening is that very small or light particles that settle slowly can be removed more completely and in a shorter time and often thicker solids can be obtained.

In most full-scale DAF units, the entire incoming flow is not pressurized and saturated with air. To save cost, a portion of the DAF effluent is recycled, pressurized, semi-saturated with air, and mixed with the unpressurized main stream just before admission to the flotation tank. The saturated air in the recycle stream comes out of solution and attaches to solids contained in the incoming stream. In addition, chemicals (coagulants such as alum or ferric chloride and/or polymer) are added to enhance the floc formation and increase the solids removal and thickening efficiency.

Critical parameters for proper design and operation of DAF units include maintaining a high air/solids (A/S) ratio, appropriate recycle ratios, sufficient pressure for dissolution of the air, and limiting the hydraulic rate for maintaining the proper clarification. Solid loading is also important when a DAF is used for thickening, as anticipated for the case at hand. To obtain sufficiently high A/S ratios, pressurized air saturation of the recycled treated effluent is typically performed. Recycle flow rates for sludge thickening can reach as high as 100 to 500 percent of incoming flow. The pressurized tank is typically maintained at 40 to 60 psig. Total hydraulic loading (including recycle) can reach as high as 4 gpm/ft^2, and retention period generally falls between 10 and 40 minutes.

Different thickening alternatives are being considered for a PLWTP that employs BAF. One alternative is to have a dedicated thickener for the BAF backwash water; another requires a unit to co-thicken the CEPT sludge and BAF backwash water. A DAF Thickener (DAFT) can provide the needed thickening process for both alternatives. Sludge character varies and can significantly impact performance and the design of the DAFT.

A bench scale DAFT unit was used to evaluate the floatability of the two types of sludges, the thickness of the sludge blanket, the sludge rise rate, and the percent solids recovery. The evaluation was performed under batch conditions and designed to determine the feasibility of using flotation as a thickening process; it was not focused on deriving a set of design criteria. It would be desirable to run a suitably sized pilot test unit to obtain design-related parameters.

NOD Impact. The presence of nitrifiers in the sample to be analyzed for $TBOD_5$ is expected to increase values for $TBOD_5$ because of the oxygen demand exerted by nitrifiers seeded into the BOD bottle with the BAF effluent. Current discharge regulations allow the use of either $TBOD_5$ or $CBOD_5$.

The City of San Diego should persue the $CBOD_5$ limit if they are to implement secondary treatment at the PLWTP. This will ensure that operational variations in the degree of nitrification in the BAF units will not jeopardize its ability to meet the effluent requirements. Brown and Caldwell suggested that a test be conducted to determine the 5-day nitrogen oxygen demand (NOD_5) of the BAF effluent to demonstrate to the regulatory agencies (i.e., the SDRWQCB and USEPA) the impact of the NOD_5 effect.

SECTION 2

WASTEWATER TREATMENT ALTERNATIVES

Primary and secondary treatment alternatives evaluated for the PLWTP under this project are discussed in this section. Other phases of wastewater treatment, e.g., preliminary treatment and solids processing, are to be evaluated during preliminary design.

Primary Treatment Alternatives

In most wastewater treatment plants, primary treatment is used to produce an effluent suitable for biological treatment by removing solids, floating debris and grease. Efficiently designed and operated systems are capable of removing 50 to 70 percent of the TSS and from 25 to 40 percent of the $TBOD_5$ contained in the influent (M&E 3rd Edition). Pre-treated (screened and degritted) wastewater is conveyed to rectangular or circular basins where solids settle within a quiescent zone. The solids are collected and treated for final disposal. Floatables are skimmed and disposed of separately. The effluent is conveyed to a downstream process. Primary treatment reduces the load on secondary process units, reducing their size and operational cost.

Existing Primary Sedimentation Basins (PSBs). Typically, the secondary process consists of a biological treatment, as discussed below. However, at PLWTP, biological treatment has not been utilized to date; instead, the PSBs were enhanced by the addition of chemicals. As a result, historical data show that the plant removed up to 89 percent of the incoming TSS and 58 percent of the incoming $TBOD_5$. Enough TSS and $TBOD_5$ are removed to allow the City to discharge the effluent directly to the Pacific Ocean and satisfy discharge requirements imposed by the SDRWQCB. A discussion on the waiver from secondary treatment was included in Section 1.

There are twelve 60-ft x 225-ft rectangular PSBs at PLWTP. With all basins operating, the surface overflow rates (SOR) at the expected ultimate average annual daily flow (AADF) of 240 mgd and peak wet weather flow (PWWF) of 432 mgd are 1,481 and 2,667 gpd/ft^2 respectively. The SOR for average conditions is slightly higher than values given in the literature (e.g., WEF MOP 8), but the deeper than typical clarifiers at the PLWTP allow for higher SORs. Note that the peak SOR is below the published ceiling of 3,000 gpd/ft^2.

High Rate Clarification. High rate clarification is a primary treatment process similar to the one described above except that manufacturers have developed ways to improve the coagulation and flocculation process by improving mixing and recirculating settled solids (in some cases with weighting agents) to aid in the settling of the solids. These improvements allow reduction in the footprint necessary to produce the performance achieved by the more land intensive CEPT process. A discussion of the two leading products in this area, Krüger's Actiflo and IDI's Densadeg systems, is provided below. Both use separate chambers for rapid mix, flocculation and settling; both also use lamella clarification for increasing the effective SOR and improved removal. Each has proven their effectiveness in full-scale applications.

Actiflo. The Actiflo process uses microsand to enhance the flocculation by providing a nucleation site where particles can be adsorbed and begin forming flocs. The microsand also has a ballasting effect, making the floc heavier and easier to settle. Rapid settling flocs enable higher overflow rates, shorter retention time, and smaller basins. Krüger reports that the required footprint is between 5 to 20 times smaller than conventional primaries of similar capacities (Krüger, April 2001). Literature provided by Krüger reports that the process is robust, achieving a constant effluent quality even during severe fluctuations in influent characteristics.

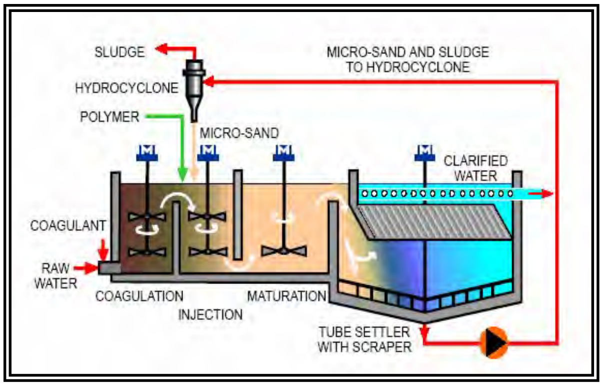

Figure 2.1. Diagram of the Actiflo Process

Removal efficiencies for TSS and $TBOD_5$ are listed at 90-95 and 50-80 percent, respectively.

The settled sludge is withdrawn from the unit and sent to a hydrocyclone where the sand is separated from the primary sludge. On the average, about 2 percent of the sand is lost to the downstream solids process, typically anaerobic digesters. The PLWTP staff has voiced some concerns about this outcome.

The pilot test team originally considered piloting this process along with the Densadeg system. However, the team discovered that the highest primary solids concentration that can be achieved is about 0.6 percent. If Actiflo were implemented, additional thickeners must be added to the treatment train to produce the desired solids concentration of 6 percent (additional digesters are not required if the resultant primaries produce sludge with this concentration). The Actiflo was not considered further after discovering this fact and the potential deposition of sand in the digesters.

Densadeg. The Densadeg high rate clarification process relies on optimized rapid mixing, flocculation, internal and external solids recirculation, and lamella (tube) settling to achieve primary treatment at reduced footprint. Sand or other components are not needed. Instead, this concept relies on intimate contact between the new, incoming solids (after passing through the rapid mix and flocculation chamber) with the solids inventory that is returned from the settling chamber. In applications at other sites, the process has managed to thicken the sludge up to 6 percent solids concentration, eliminating the need for additional thickeners. In some applications, solids concentrations reaching 10 percent have been observed.

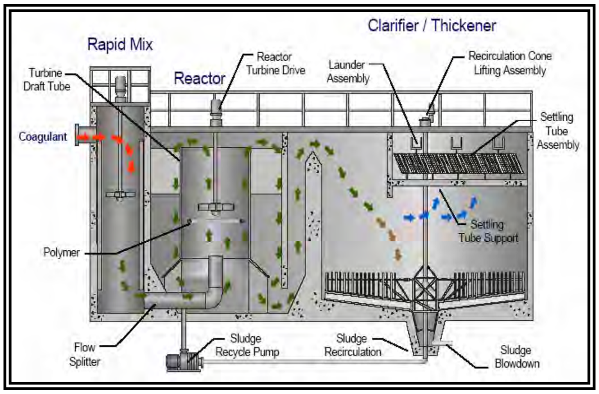

Figure 2.2. Densadeg High Rate Clarification Process

Densadeg can be used for primary treatment, tertiary treatment, phosphorus removal, and thickening. Currently, there were 77 full-scale Densadeg applications worldwide; 52 of the 77 were for primary treatment. Six facilities in Canada, ranging in size from 14 to 168 mgd, use Densadeg for primary treatment. There are five in the United States – four for tertiary treatment and one for filter backwash thickening.

The advantage of thicker sludge and the absence of microsand addition made Densadeg a more suitable high rate primary treatment process to evaluate for application at the PLWTP. After reaching this conclusion, the pilot test team proceeded to contact and acquire from IDI a budget proposal and concept drawings for a full-scale system. Plans for pilot testing a Densadeg unit in Phase II were also formulated.

Secondary Treatment Alternatives

Secondary treatment alternatives for the PLWTP were assessed in early 1990. The following treatment alternatives were considered:

- Air Activated Sludge (AAS)
- Oxygen Activated Sludge (OAS)
- Trickling Filter (TF)
- Trickling Filter/Solids Contact (TF/SC)
- Physical/Chemical (P/C)
- Land Treatment
- Rotating Biological Contactors (RBC)
- Aquaculture with Water Hyacinths
- Biological Aerated Filter (BAF)
- Sequencing Batch Reactor (SBR)
- Coordinated Chemical Bonding and Adsorption (CCBA).

Because of the PLWTP site's land constraints and the known reliability of the process to produce secondary effluent that meets standards, OAS and TF/SC were deemed to be the best choice for PLWTP. However, the lack of available land and the size of the OAS and TF/SC facilities limited the AADF capacity to 150 mgd.

Although the BAF process was considered to be "very promising," the lack of a long track record, the small number of applications in the United States and the rest of the world, and the absence of facilities with capacities greater than 15 mgd, this technology was not explored further. However, the study recommended pilot testing the BAF process because of its great promise.

There have been several changes, improvements and innovations since the 1990 secondary treatment evaluation conducted for the City. Recently, the City requested Brown and Caldwell to revisit and reevaluate potential secondary treatment alternatives for the PLWTP. Brown and Caldwell developed a matrix, shown in Appendix A, providing process names, descriptions and current vendors. Each process was also numerically rated on how well it met a set of criteria defined by the City, including footprint, proven effectiveness, experience, performance and life-cycle cost. The City and Brown and Caldwell collaborated in developing the weights assigned to each criterion.

It is important to note that the evaluation excluded physical/chemical (P/C) technologies (such as adsorption with carbon and other media, ozonation, chemical oxidation, coagulation, precipitation, and electrolysis), because investigations conducted by the USEPA in the 1970s and 1980s indicated that, in general, P/C plants are more expensive in terms of capital and operations and maintenance (O&M) costs than biological treatment systems. In addition, almost all P/C plants have been abandoned because of poor performance or high operating costs or design flaws.

The top four biological treatment options identified by the recent (2004) assessment and their relative scores are summarized in Table 2.1.

Table 2.1. Top Four Biological Treatment Options for the PLWTP

	Criteria Score (Criteria Weight)					
Option	Footprint (30)	Proven Effectiveness (25)	Experience (15)	Performance (15)	Life Cycle Cost (15)	TOTAL (100)
BAF	30	15	15	15	7	82
MBR	30	0	15	15	5	65
AAS	0	25	15	15	10	65
OAS	0	20	15	15	10	60

MBR, AAS and OAS generally fell within the same level, i.e., a distant second, for several reasons. The zero score received by MBR under “Proven Effectiveness” reflects the absence of an MBR facility with a capacity greater than 30 mgd. Furthermore, discussions with MBR manufacturers indicate that, at this time, supplies of membrane and membrane manufacturing facilities are insufficient to support the construction of larger MBR facilities. Both the OAS and AAS processes scored poorly on the footprint criterion when compared to the lower-land-impact options such as MBR and BAF. The BAF evaluation was boosted significantly by the experience gained by the vendors since 1990 in large plant applications. It was concluded that, to date, BAF was the most viable technology for PLTWP and pilot testing should be performed to develop design criteria or confirm those proposed by the BAF vendors.

Biological Aerated Filters. The BAF process is a biological treatment technology that can provide secondary treatment of municipal and industrial wastewaters. BAFs are submerged fixed film biological reactors in which microorganisms, attached to reactor media and occupying the interstices of the media bed, reduce the carbonaceous and/or nitrogenous content of the incoming wastewater. The reactor media also retains insoluble solids (TSS) present in the incoming wastewater and those generated within the reactor, thus eliminating the need for a separate clarification process. Excess microbial growth and trapped solids are purged from the reactor by backwashing with treated wastewater to make room for new microbial growth. Backwash cycling can be automated to initiate on differential pressure (headloss) or on run-cycle-time. BAF systems exist in both upflow (co-current) or downflow (countercurrent) arrangements. In addition to wastewater flow direction, BAFs can be differentiated further by media type and size. Both floating and sinking media systems are available commercially.

BAFs can be configured for $CBOD_5$ removal, nitrification and/or denitrification. In fact, BAFs are commonly used for nutrient removal following AAS. Alternatively, the BAF system can completely replace the AAS process. Two-stage BAF systems are commonly used when nitrification is required and footprint is an issue. In this scenario, the first unit is sized for $CBOD_5$ removal and the second unit is sized for nitrification. When this is done, the first stage is referred to as the "C" stage and the second as the "N" stage. A third anoxic stage can be added for denitrification. In some cases, two "C" stages in series (the last stage is often "C" + "N" during hot weather) must be used to adequately treat the wastewater and meet $TBOD_5$ discharge limits.

BAF Options. There are several different types of BAF units in the market today. As stated above, the BAF can be configured to run in the upflow or downflow direction. A list of some of the larger upflow and downflow filters commercially available is provided below:

- Downflow BAF Systems
    - ✓ Denite
    - ✓ Biocarbone
    - ✓ Biodrof
- Upflow BAF Systems
    - ✓ Biofor
    - ✓ Biostyr
    - ✓ Biobead
    - ✓ Biolest
    - ✓ Biopur

The downflow filters were the first available commercially. This configuration introduces wastewater at the top of the media and applies air at the bottom. This countercurrent arrangement suffers from uneven distribution of the air and dramatic increase in headloss at high solids loading, requiring frequent backwashing.

The upflow filters introduce wastewater at the bottom of the filter. The wastewater proceeds upwards in the same direction as the air. This upward flow ensures an even distribution of water and air and acts to reduce short-circuiting and gas entrapment. The media retains solids and biomass throughout the entire bed depth, allowing longer run times between backwashes. It also facilitates effective use of the applied air by forcing the air and the wastewater to rise through the media, improving contact times and transfer efficiencies.

Interest in downflow filters has recently diminished such that all BAFs constructed lately are of the upflow (co-current) configuration. The two most frequently used upflow filters are Biostyr and Biofor filters. The other upflow filters do not have a similar long term track record and/or have small (<30 mgd) facilities online.

The City solicited and received preliminary proposals from the top two makers of upflow BAF systems: Infilco Degremont, Inc. (IDI), maker of the Biofor process, and Krüger, manufacturer of the Biostyr process. Each proposal contains performance assumptions and criteria related to

PLWTP wastewater that must be verified prior to upgrading the PLWTP with the proposed BAF process. For this reason, pilot testing of each of the proposed BAF systems was required.

Biofor. Biofor reactors contain a submerged, fixed, and heavy media bed. Influent wastewater flows upward through the media, co-current with the air provided for aerobic decomposition of organics or nitrification. The media, called Biolite, is an expanded clay material with high specific surface area that ensures good biomass attachment. The media is of high density and has good resistance to attrition. It ranges in size from 1 to 5 millimeters (mm), depending on the application. The larger size media is used for carbonaceous oxidation; the resulting high media porosity allows sufficient volume for the growth of heterotrophic fixed films without undue pore blockage.

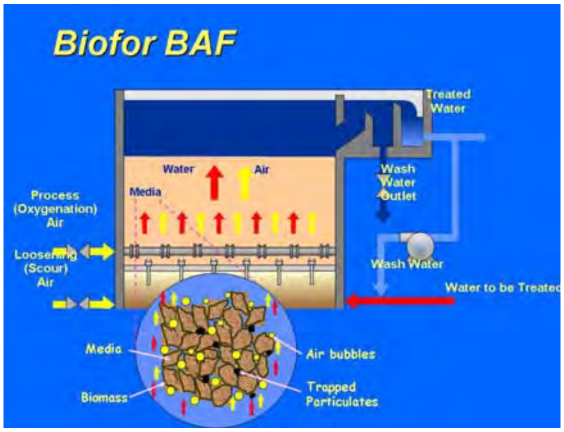

Figure 2.3. Biofor BAF

At the bottom of the media bed, directly above a plenum that contains nozzles through which wastewater passes, is an air distribution network consisting of pipes fitted with proprietary coarse bubble air diffusers called Oxazur. Diffused air and gas retention within the media results in oxygen mass transfer characteristics similar to fine bubble diffusion.

The nozzles embedded in the plenum (i.e., media floor) encourage even distribution of the incoming wastewater. Screens with 2.5 mm openings are required to prevent the nozzles from clogging. Clogged nozzles will cause poor distribution and resulting reduced process efficiency as well as increased pressure headloss across. Nozzle cleaning requires shutting down the cell and removing the media to access the nozzles.

Biofor units are backwashed in an upward (co-current) direction. The water used for backwashing is typically Biofor effluent stored in a separate tank and pumped upward through the media during backwash sequences. Generally, backwashing is required every 24 hours or more. The backwash solids are stored in a separate basin sized to minimize the impact of the backwash waste (typically returned to the headworks or the head of the PSBs). Some facilities direct the backwash to a thickener to remove as many solids as possible before discharging it to the headworks. Media loss can occur if the backwash is performed too aggressively or if the media blend contains granules with a lower density than required. About 2 percent annual media loss has been observed in full-scale operating facilities.

The Biofor process can be configured for carbonaceous removal (Biofor-C) or for nitrification (Biofor-N). The systems can be used singly or in series to achieve the desired removal.

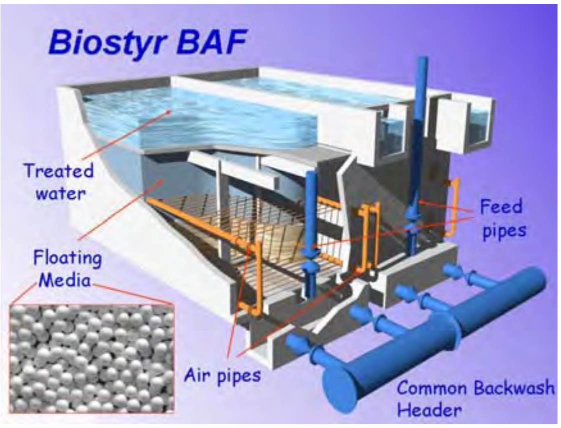

Figure 2.4. Diagram of the Biostyr System

Biostyr. The Biostyr system is also an upflow submerged fixed-film filter that biologically treats carbonaceous wastes and removes insoluble pollutants (TSS) through a filtering mechanism. It differs from the Biofor unit in its use of a floating media made of high density polystyrene beads, called Biostyrene. The media floats because of its low density (relative to water) and so the plenum for retaining the media is located above the media rather than below it. The nozzles located in this plenum are, therefore, in contact with treated water rather than screened influent, minimizing the potential for nozzle clogging. Krüger has indicated that a 10 mm screen, the same screen spacing installed at the PLWTP headworks, is appropriate for Biostyr systems. The floating media also makes nozzle maintenance easier should one need to be replaced or unclogged. The cell need not be emptied completely of media; instead, the cell would be drained, allowing access to the nozzles located at the top of the cell.

The Biostyr system can be designed to achieve carbonaceous removal, nitrification, and/or denitrification; carbonaceous removal and nitrification can occur in the same cell. The use of floating media, which ranges in size from 3 to 6 mm depending on the application, results in unique hydraulics during process and backwash runs. Influent wastewater is pumped to a common feed channel located above the reactor cells. After flowing by gravity to the bottom of the cell, the wastewater subsequently flows upward through the floating media. For carbonaceous and/or nitrification, air is introduced at the bottom of the media. Nitrification will begin to occur in the bed once a limiting $TBOD_5$:Total Kjeldahl Nitrogen (TKN) ratio is reached. The treated water flows to a separate clean water channel above the cells.

During backwash, valves are manipulated to allow the treated water from the clean water channel to gravity flow downward through the cell. This action expands the filter media. Backwashing is enhanced by increasing the air flow during this period. The backwash stream flows through a floor underdrain to a separate backwash basin sized to minimize the impact of the backwash waste (typically returned to the headworks or the head of the PSBs). As with the Biofor system, some facilities direct the backwash to a thickener to remove as much solids as possible before discharging it to the headworks.

The control of Biostyr hydraulics is more complex in that velocities during backwash are controlled to minimize the loss of the Biostyrene beads. Media loss can occur when the Biostyrene beads are compressed and agglomerate into a bigger mass such that, during backwash, the large mass is carried away through the underdrain. Media loss can also occur if the nozzles suffer a rupture. About 2 percent annual media loss has been observed in operating systems.

SECTION 3

PILOT TEST PLAN AND IMPLEMENTATION

The planning, methodology, materials, and scheduling that formed the structure of the 43-week BAF pilot test effort at PLWTP are described in this section. The events that took place during the testing are also discussed, including activities that deviated from the original plan.

Pilot Test Criteria

The pilot test was conducted to determine the performance of BAF and HRCT pilot units operating at full-scale flow and load conditions. Historical plant data for the years 1996 through 2001 were used as the basis for the planned loadings to the pilot units shown in Table 3.1. CEPT effluent characteristics shown in Table 3.1 reflect the quality of effluent produced by the existing PLWTP for the 5-year period. It was expected that the selected HRCT, if implemented, can produce effluent of similar quality.

IDI and Krüger were provided the information in Table 3.1 to develop preliminary facility design, equipment layout and cost estimates. The main features of the BAF facility designs provided by each manufacturer are provided in Table 3.2. Design hydraulic, organic and solids loading values used in the proposals are listed in Table 3.3. Unit loadings reported by the manufacturers did not include the backwash recycle flow. The design criteria proposed by IDI for the Densadeg system are shown in Table 3.4. Proposals for all three systems are provided in Appendix B.

Table 3.1. Design Flow and Load Conditions for PLWTP BAF Facilities

Design Parameter	Units	Value at Specific Conditions		
		Average Annual Daily Flow	Maximum 30-day Rolling Average	Peak Hour Wet Weather Flow
Flow	mgd	240	264	432
CEPT Effluent $TBOD_5$ concentration	mg/L	96	116	
CEPT Effluent TSS Concentration	mg/L	42	52	
CEPT Effluent TKN Concentration	mg/L	42	68	

Table 3.2. Proposed Full-Scale BAF Facility Parameters

Item	Units	IDI - Biofor-C(a)	Krüger – Biostyr(b)
Number of BAF Cells	NA	64	40
Cell Length	ft	42.25	57.00
Cell Width	ft	38.2	45.3
Horizontal Cross-Sectional Area per Cell	ft^2	1,613	2,582
Total Horizontal Cross-Sectional Area	ft^2	103,212	103,280
Media Column Height	ft	12.10	11.48
Media Bulk Volume per Cell	ft^3	19,513	29,641
Total Media Bulk Volume	ft^3	1,248,861	1,185,654

(a) Based on December 12, 2003 (IDI Proposal No. 512-3999) proposal from IDI.

(b) Based on November 21, 2003 proposal from Krüger.

Table 3.3. Design Criteria Proposed by BAF Vendors

Parameter	Units	IDI(a)		Krüger (b)
		Biofor-C	Biofor-N	Biostyr
TBOD$_5$ loading rate (MM)	lb/1000 ft^3-day	224	90	218
TSS loading rate (MM)	lb/1000 ft^3-day	100	45	99.7
Hydraulic loading rate (MMF)	gpm/ft^2	1.9	3.9	2.0
Hydraulic loading rate (PWWF)	gpm/ft^2	3.0	6.0	2.9
Process air supply (MMF) (c)	scfm/ft^2	0.52	0.52	0.85
Backwash air	scfm/ft^2	5.35	5.35	0.65

lb = pound
ft^3-day = cubic feet-day
MM = Maximum Month
MMF = Maximum Month Flow
PWWF = Peak Wet Weather Flow
scfm = standard cubic feet per minute
ft^2 = square feet

(a) Based on December 12, 2003 (IDI Proposal No. 512-3999) proposal from IDI.

(b) Based on November 21, 2003 proposal from Krüger.

(c) Note that the vendor proposals were based on max month air requirements. Peak day and peak hour air requirements will need to be assessed for detailed design.

Table 3.4. Full-Scale Densadeg Design Criteria Proposed by IDI

Item	Proposed Value
Design Flows, mgd ▪ Maximum month ▪ Peak	 264 432
Number of Units	16 (SL-140 Model)
Nominal Flow per Unit, mgd/unit	22
Nominal Loading Rate (over settling tube), gpm/ft^2	10.25
Peak Flow per Unit, mgd/unit	27
Peak Loading Rate (over settling tubes), gpm/ft^2	12.4
Dimensions per Pair ▪ Length, ft ▪ Width, ft ▪ Height, ft	 81 105 28
Total Area Occupied by System Proposed, ft^2 (including Influent and Effluent Trough and Rapid Mix, Reactor and Settling Basins)	85,272 (374-ft x 228-ft)

Based on the December 12, 2003 proposal (IDI Proposal No. 512-3999) from IDI.

The primary treatment system proposed by IDI would occupy roughly the same area as six existing PSBs. The corresponding SORs at maximum month and peak conditions for the Densadeg are 14,800 and 17,900 gpd/ft^2 (converted from loadings rates reported in Table 3.4). This is about 9 and 7 times, respectively, higher than the SOR estimated for the existing PSBs. One would expect that the Densadeg can fit in the area occupied by two PSBs, but the proposed system described in Table 3.4 includes influent and effluent troughs and rapid mix and reactor basins, which occupy a fairly significant footprint.

Pilot Test Schedule and Events

The pilot test consisted of (1) the design of the pilot test system; (2) the construction of the concrete pad where the pilot units and storage tanks were placed and associated piping and electrical components; (3) the 43-week testing of the pilot units and (4) preparation of this final report. The pilot test schedule is presented in Table 3.5.

Table 3.5. Pilot Test Schedule

Pilot Unit	Phase	Experiments	Week No.	Date
Biostyr	I	Startup	---	Mar 7–Mar 21
	I	Experiment 1	(a)	
	I	Experiment 2	6	Mar 22–Apr 4
	I	Experiment 3	7-14	April 5-May28
	II	Densadeg Testing	28-29 & 33-40	Sep 2-12 & Oct 5-Nov 22
	--	Off-gas Testing(b)	42	Dec 6-13
	--	Stress Test	43	Dec 14-17
Biofor-C	I	Startup	---	Jan 26–Feb 22
	I	Experiment 1	1-2	Feb 23–Mar 7
	I	Experiment 2	3-6	Mar 8–Apr 4
	I	Experiment 3	7-14	April 5-May28
	II	Densadeg Testing	28 & 33-40	Sep 2-5 & Oct 5-Nov 22
	--	Off-gas Testing(b)	42	Dec 6-13
	--	Stress Test	43	Dec 14-17
Biofor-N	I	Startup	---	Jan 26–Feb 22
	I	Experiment 1	1-2	Feb 23–Mar 7
	I	Experiment 2	3-6	Mar 8–Apr 4
	I	Experiment 3	7-12	Apr 5–May 16
Densadeg	II	Densadeg Testing	28-29 & 33-40	Sep 2-12 & Oct 5-Nov 22
	---	Stress Test	41	Dec 2-3

(a) The Biostyr unit was not operated under Phase I - Experiment 1 conditions. The Biostyr unit experienced startup problems that included a failed backwash valve, failed influent pump, and rain intrusion to the electrical cabinet. The startup period was initiated after these issues were resolved. The unit was placed into full operation in the middle of the Experiment 2 period.

(b) The BAF units were operated using CEPT effluent from the existing PSB at the PLWTP. Units were operated at 2.0 gpm/ft^2 hydraulic loading.

Figure 3.1. BAF Pilot Units

Construction began soon after the City of San Diego Building Services Department approved design plans and specifications for the pilot test system in November 2003. It continued until January 26, 2004, when startup and acclimation of the BAF pilot units began. Meanwhile, Krüger and IDI staff trained the City and Brown and Caldwell staff on the operation of the pilot units; the sampling equipment was also installed at this time. The reactors were fed with the PLWTP CEPT effluent during the startup period at a rate of 1.5 gpm/ft^2 to establish a biofilm on the media. Effluent turbidity and occasional TSS and COD analyses were performed to track the biofilm maturation process, which required approximately two weeks.

The Biostyr unit experienced several mechanical and electrical problems at startup (see Appendix C for details). Consequently it was not ready to be monitored until Week 5. The Biofor-C and Biofor-N also experienced some problems (detailed in Appendix C), but they were not as severe such that effluent quality slowly improved as the biofilm matured.

Phase I. On February 23, 2004, the full sampling program for Phase I of the pilot test began. A process flow diagram describing the Phase I pilot unit arrangement is shown on Figure 3.2. Phase I consisted of three experiments. Heavy rains allowed the team to immediately test the Biofor-C and the Biofor-N processes under a peak wet weather hydraulic loading rate of 3.0 gpm/ft^2 during Experiment No. 1. Experiment No. 2 consisted of testing the Biofor-C and Biofor-N processes at intermediate hydraulic loading rates between 2.0 to 3.0 gpm/ft^2. During the last week of Experiment No. 2 (around Week No. 6), effluent sampling of the Biostyr unit began after several weeks of repair and two weeks of acclimation. Experiment No. 3 was conducted between April and May when dry weather conditions prevailed. The units were operated at the proposed maximum month condition, or 2.0 gpm/ft^2, for the remainder of the Phase I period.

Each pilot unit required backwashing at regular intervals to eliminate excess biomass and accumulated particulate material from the columns. The interval for the Biofor-C and Biostyr units was set at 24 hours; the Biofor-N backwash interval was 48 hours. The specific backwashing sequence, established by the manufacturers, was different for each unit. Generally, the backwashing sequences consisted of repetitions of relatively high velocity flushing alternating with relatively vigorous air sparging. The backwash water used by the units was the effluent from that unit. One exception to this figured prominently in the conclusions of the study. For all of Experiment Nos. 1 and 2 and most of Experiment No. 3, the Biofor-C process was backwashed using effluent from the Biofor-N process. This approach was changed for reasons discussed in Section 4.

The Densadeg pilot unit was delivered at the end of May, and installed and activated on June 2, 2004. The BAF pilot units were placed in idle mode during the installation of the Densadeg unit; i.e., no influent flow, but process air was provided to prevent septicity.

Phase II. A process flow diagram describing the Phase II pilot unit arrangement is shown on Figure 3.3. It should be noted that Figure 3.3 depicts the Biofor-N in the process configuration. However, it was discovered after review of the Phase I results that the expected standards for ocean disposal of secondary treated wastewater could be met with a single-stage BAF design for carbonaceous removal only (Biofor-C). Therefore, the Biofor-N pilot plant was not operated during Phase II. Phase II was originally planned to occur between June and September 2004. However, unplanned and unforeseen events caused significant delays. These events included:

- **Replacement of the Densadeg pilot influent pump.** The original pump installed on the delivered unit was intended for tertiary or water treatment. Rags and debris in the raw wastewater caused the pumps to plug. Pump replacement did not occur until mid-July, a six week setback.

- **Failure and replacement of sludge recirculation pump.** Pump failure caused poor performance due to inability to recirculate sludge. Sludge recycle is one of the main process parameters for good Densadeg performance.

- **Replacement of a butterfly valve.** This valve was located between the flash mix tank and the reactor chamber. It was prone to plugging, diminishing the flow to the reactor and settling chambers. Butterfly valves are more suited for applications with no significant amount of rags, hair and other debris. The butterfly valve was replaced with a gate valve in mid-September.

- **Polymer optimization.** IDI spent several weeks testing several polymers and finally selecting a polymer that provided consistent results. Pump failures required polymer optimization to be performed many times.

- **Clogging of sludge outlet tube.** The outlet tube (also the intake to the sludge recirculation pump) clogged resulting from a buildup of solids and hair caught on a pen that had been trapped in the tube. The stored solids became septic, generating gas bubbles that floated the sludge. The Densadeg unit had to be flushed and chemical polymer optimization reinitiated.

- **Grit system construction.** The Densadeg pilot plant received screened, non-degritted raw wastewater up to the installation of a hydraulic vortex (Eutek Teacup) type grit removal system on October 14, 2004. There were concerns that the grit may be improving the removal efficiency of the Densadeg unit by providing a ballasting effect like the microsand used in the Actiflo system. Since the full scale system will receive degritted wastewater, a grit removal system was installed.

Because of these events, the Densadeg unit operated continuously for only two periods: between September 2 to September 12 and between October 5 to November 22, 2004. Data collected during the latter period were used to assess its performance due to the mechanical and chemical problems described above. Process flow diagrams describing the Phase I and Phase II configuration is provided on Figures 3.2 and 3.3.

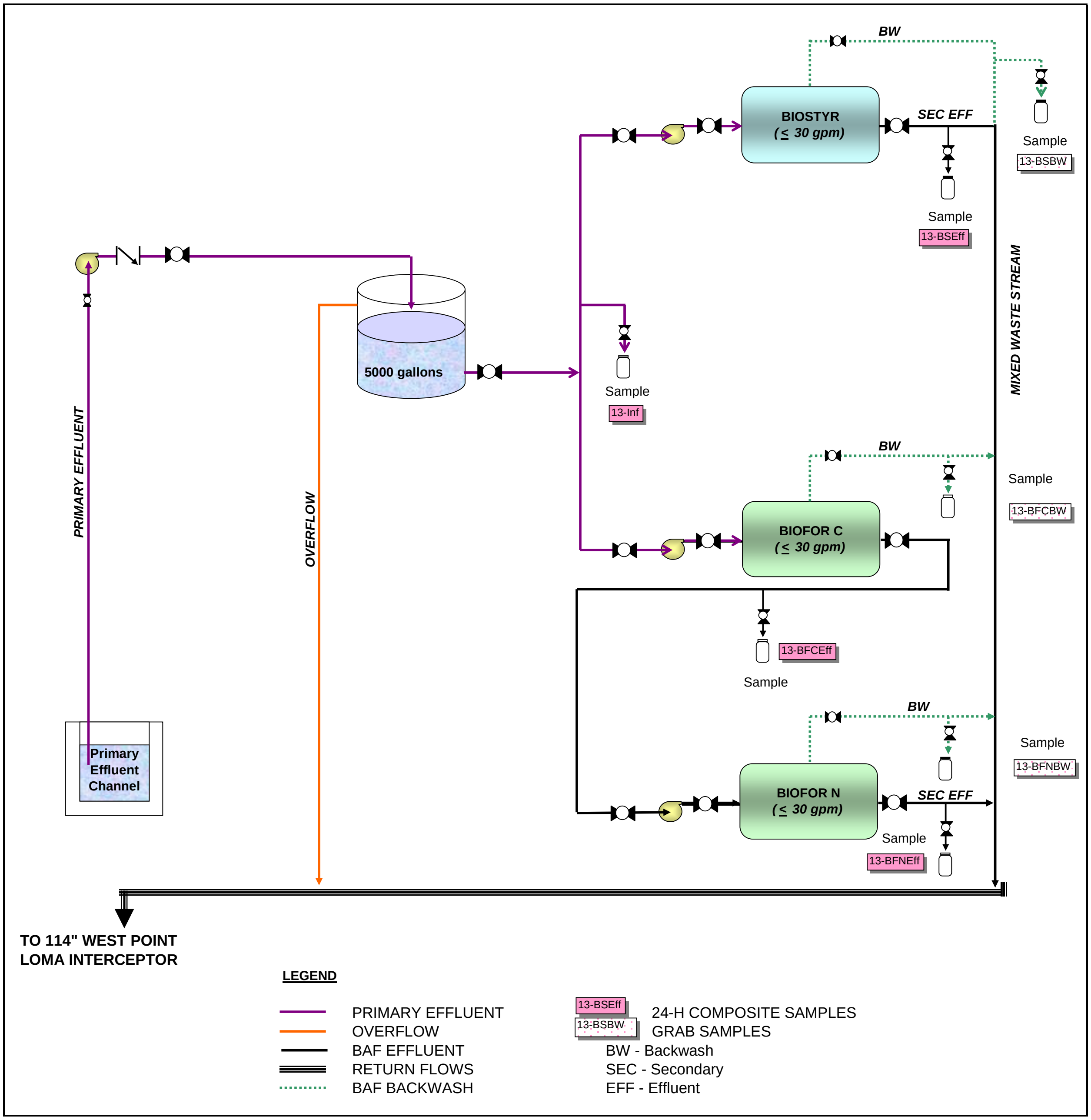

Figure 3.2. Phase I BAF Pilot Test Process Flow Diagram

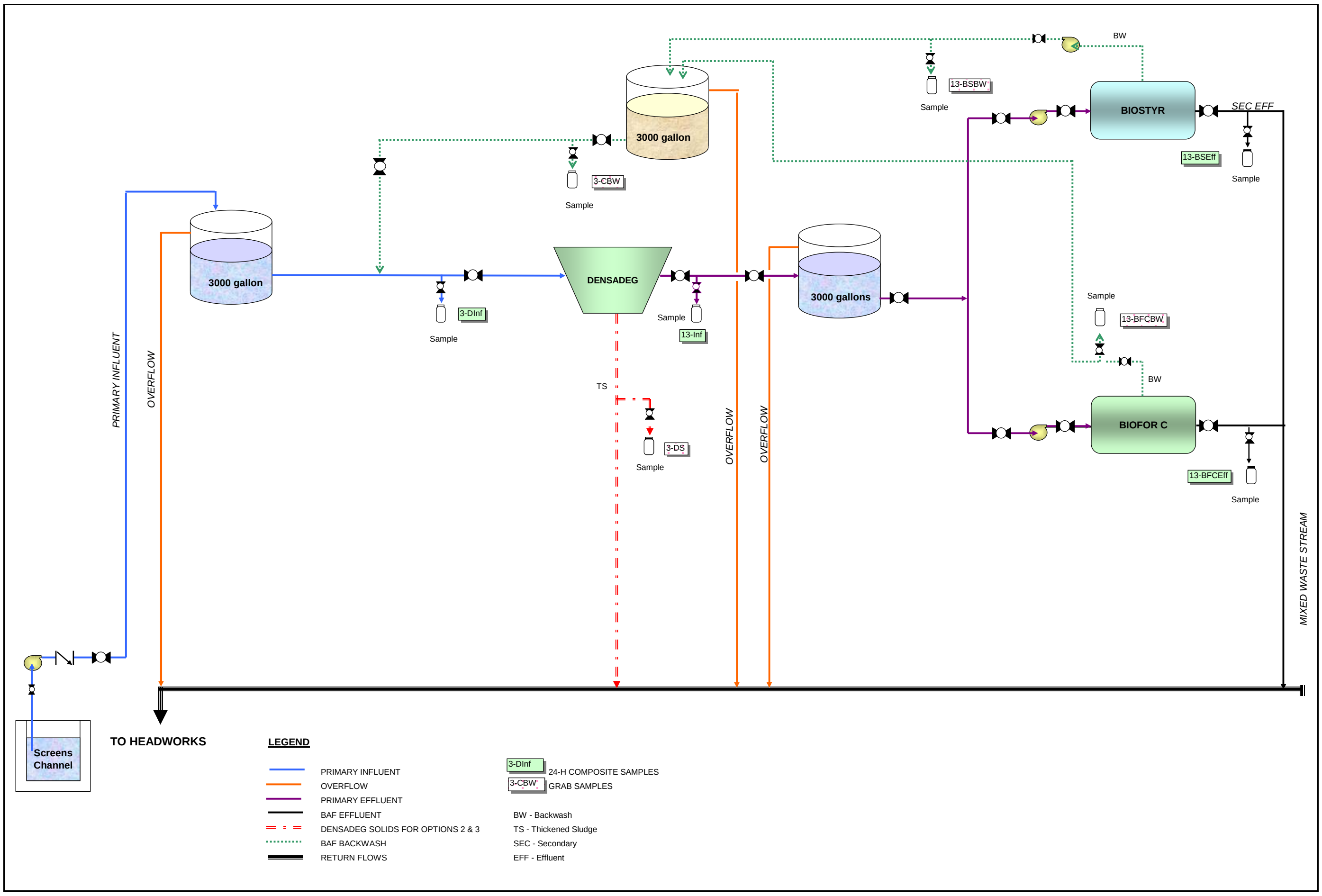

Figure 3.3. Phase II BAF Pilot Test Process Flow Diagram

Off-Gas Testing. Off-gas testing was performed to assess the oxygen transfer efficiency in the BAF. Dr. Michael Stenstrom of the University of California at Los Angeles conducted tests on two separate occasions; each event lasted for two consecutive days and both BAF pilot units were tested. The first test occurred on May 13 and 14, 2004, during Phase I. Biofor-C process blower malfunction and potentially septic and poor air distribution witnessed in the Biostyr resulted in questionable oxygen transfer efficiency values. Concerns by the City, BC, and the pilot unit manufacturers necessitated running a second test. On December 12 and 13, 2004, another off-gas test was performed after the Phase II testing of the Densadeg had ended. At this time, the BAF pilot units had begun treating the PLWTP CEPT effluent as they did in Phase I. The Biostyr and Biofor-C performed without incident during the second test.

Figure 3.4. Photo of Media in Biostyr Column as Seen Through Observation Window

Stress Testing – Densadeg. Stress testing of the Densadeg pilot plant occurred after the 2004 Thanksgiving holiday, occurring on December 2 and 3, 2004. Before the holidays, IDI ceased operating the Densadeg (signifying the end of Phase II) and drained the unit, eliminating the need to monitor and maintain it with the limited staff available. IDI also drained and cleaned the 3,000-gallon Densadeg Influent Tank (DIT) to remove any solids deposited in the tank over the previous test period. There were concerns that sulfides were being generated within the mass of deposits and possibly impacting performance over the stress testing period.

After the holidays, the IDI staff returned and began preparing the Densadeg unit for the test. Sludge blanket and wasting rates were adjusted, and several ferric chloride and polymer dosages were tried to determine the appropriate operating parameters that would consistently produce TSS effluent concentration of 65 mg/L or lower at a hydraulic loading rate (HLR) of 12.4 gpm/ft^2. Note that 12.4 gpm/ft^2 is the operating hydraulic loading rate proposed when the PLWTP receives 432 mgd of flow.

The Densadeg pilot unit was operated at an average flow of 130 gpm. Slight plugging of the piping that extended from the PSB to the pilot test pad caused excessive headloss, preventing the delivery of the PSB effluent at 134 gpm, the rate equivalent to 12.4 gpm/ft^2, assuming a lamella cross sectional area of 10.75 ft^2 as given by IDI (the pipes were found to contain a 1/8-inch layer of black slimy material during the demolition of the pilot test apparatus). The Densadeg actually operated at a hydraulic loading rate of 12.07 gpm/ft^2 for 24 hours.

Stress Testing – BAF. Stress testing of the BAF pilot units was conducted on December 14-17, 2004, immediately after the stress testing of the Densadeg. The transition from the Densadeg stress testing to the BAF stress testing required some reconfiguration of the pumping and piping to allow the BAF units to be fed with effluent from the PLWTP PSB. After the reconfiguration, the BAF units were allowed to stabilize before the effluent was sampled and monitored.

The BAF units were operated initially at 2 gpm/ft^2. Stress testing began right after the backwash, i.e. with a clean column. In order to start stress testing for both BAF units at the same time, it was required to perform both backwashes at the same time.

Operational set points (OSP) for the BAF units were determined based on the following scenarios:

- OSP1 - 10 percent of the cells are assumed to be out of service (proposed by the BAF vendors)
- OSP2 - 22 percent of the cells are assumed to be out of service (OOS)
- OSP3 - 33 percent of the cells are assumed to be OOS
- OSP4 - 42 percent of the cells are assumed to be OOS.

The four operational set points are summarized in Table 3.6.

Table 3.6. BAF Stress Testing Operating Conditions

Item	Biostyr	Biofor-C
Total number of cells proposed	40	64
Peak hourly flow, mgd	432	432
Size of a cell, ft^2	2582	1612.5
Operating Set Point	Hydraulic Loading Rate (HLR), gpm/ft^2	
OSP1	3.2 (4 cells OOS)	3.2 (6 cells OOS)
OSP2	3.8 (9 cells OOS)	3.7 (14 cells OOS)
OSP3	4.3 (12 cells OOS)	4.3 (21 cells OOS)
OSP4	5.1 (17cells OOS)	5.0 (27cells OOS)

The idea behind the stress test was to simulate a shock loading event by increasing the hydraulic loading rate (HLR) over a period of approximately 20 hours and observe the treatment capacity provided by the BAF units under the high loading conditions.

Each OSP was conducted within a 24-hour period and testing proceeded as follows:

Hour 1:	Aggressively backwash the column
Hour 2 to 3:	Slowly ramp up HLR from 2.0 gpm/ft^2 to target HLR noted above
Hour 4 to 24:	Operate at target HLR while taking hourly influent and effluent samples.

This process was repeated for each OPS. Hourly monitoring of the BAF units during the stress test consisted of observing the following parameters:

- Influent and effluent turbidity
- Influent flow rate
- Process air flow rate
- Biofor C and Biostyr column pressures
- Time between backwashes.

Other Tests. Other tests, namely the NOD, Media Sampling, and DAFT Feasibility, were all performed during Phase II. Media sampling was unsuccessfully attempted in Phase I; however, successful collection of media did not occur until Phase II.

Sampling Protocol

The Phase I and II sampling protocols are provided in Appendix D. Some key sampling and monitoring parameters are described below.

Daily Composite Sampling. Daily time-based composite samples were collected from the influent and effluent streams of the Biostyr, Biofor-C, Biofor-N, and Densadeg pilot units. Refrigerated autosamplers, set at 4°C, were programmed to collect a 100-mL sample every 15 minutes. This produced a composite sample (approximately 7.2 L), which was divided into various sample bottles for analysis.

Daily Monitoring.

Meter Readings. Meter readings of influent, effluent and backwash waste streams from each BAF pilot unit were measured and recorded daily by the City and Brown and Caldwell staff using portable meters calibrated daily. The daily unit meter readings were recorded in daily log sheets. The following parameters were measured for each process stream:

- temperature
- dissolved oxygen concentration
- pH
- ultraviolet transmittance (UVT)
- turbidity

Pilot Instrument Readings. Each day, the sampling crew recorded information taken from each of the BAF and Densadeg pilot units.

Headloss Measurements. Pressure transducers installed on each BAF pilot unit determined the pressures at four locations along the height of the bed: one at the bottom, one near the top, and two in between to obtain the headloss across BAF media column. Continuous measurement of the headloss also aided in tracking backwash events, determining the best time to backwash, exhibiting the plugging or biogrowth patterns along the height of the column, and evaluating the effectiveness of each backwash in removing excess solids, thereby reducing the pressure loss along the column.

Figure 3.5. Photo of Pressure Transducer Mounted on BAF Column

Backwash Grab Sampling and Monitoring. Each of the BAF pilot units was backwashed on a specific interval (initially every 24 hours). Backwash times were adjusted so that only one BAF unit backwashed at a time. Because of the variability in solids content of the backwash process, it was decided to collect and sample the total backwash volume. Backwash water was collected on a batch basis in a backwash tank, mixed by a pumped mixing system and then sampled. The mixing pump was turned on after backwash was completed. The pump ran for some time (about 3-5 minutes) to ensure that complete mixing was achieved in the tank. Every other day, a backwash sample was taken from the discharge line of the mixing pump. After the sample was taken, the pump turned off, and the backwash tank drained and hosed off to clean the tank for the next backwash event. Backwash samples were analyzed for total suspended solids, volatile suspended solids, total solids, volatile solids, chemical oxygen demand, settleable solids, and total phosphorus (the latter only on a few occasions).

Settleability of Backwash Solids. Two times per week, backwash samples were taken to perform the settleability test. This consisted of pouring a 1-L backwash sample into an Imhoff cone and recording the time and location of the clearwater and settled solids interface. An SVI (sludge volume index) value was derived from this process coupled with TSS data from the associated mixed backwash sample. After performing the Imhoff cone test, the supernatant was analyzed for $CBOD_5$, TSS, and VSS. The settled solids in the Imhoff cone were analyzed for TS and VS.

Figure 3.6. Photo of Backwash Sample Settling in Imhoff Cone

Sampling and Monitoring Diurnal BOD_5. On two occasions, autosamplers were used to collect 2-hour time-based composites to measure diurnal $TBOD_5$ variability. The first set of samples was analyzed for $TBOD_5$ and $SBOD_5$. The second set was analyzed for $CBOD_5$ and $CSBOD_5$. The BAF influent flow rate remained constant during the period of diurnal BOD testing.

Coliform and MS2 Bacteriophage Testing. The study included limited virus, total coliform and fecal coliform, and *Enterococcus* testing. Coliform and MS2 Bacteriophage testing was performed twice per week on influent and effluents of the Biostyr, Biofor-C, Biofor-N and Densadeg pilot units.

Bioassay. Ultimately, effluent from the PLWTP must pass the toxicity requirements for discharge to the Pacific Ocean. The BAF effluent was tested for toxicity on giant kelp once per month and on *Mysidopsis bahia* twice per month. These same organisms are used by the City to determine the toxicity of the CEPT effluent currently being discharged.

Collimated Beam Analysis. Collimated beam analysis was performed five times during Phase II to determine the possible ultraviolet (UV) disinfection required to achieve certain log deactivation. The data can be used to size a UV system that may be needed in the future. An external lab was used to perform the tests.

Laboratory results are provided in Appendix E. A discussion of the results is presented in the next section.