Increasing the capacity of wastewater treatment plants in Oslo by process transitions during high flows

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SEVENTH FRAMEWORK PROGRAMME

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Contents

1 Background

1.1 General

Increased occurrence of high intensity rainfalls will strongly influence the municipal sewerage system. Combine sewer systems (CSS) transport storm water and municipal wastewater. During high intensity rainfalls the capacity of the combined sewers systems will be exceeded, resulting in the discharge of combined storm water and untreated wastewater to receiving waters. Combined sewer overflows (CSOs) can introduce high concentrations of microbial pathogenes and other pollutants into the recipient. Generally, CSOs can represent a threat to the public health as a result of contamination of drinking water sources and bathing water. Several measures can be introduced to prevent the negative effects of CSOs, e.g. storm water management to reduce the volume of storm water entering the combined sewer network and increased capacity of the sewer network, for instance use of storm water retention basins. A higher capacity of the sewer network makes it necessary to increase the capacity of the wastewater treatment plant.
This report gives a general description of how the treatment plant capacity is increased during high flow conditions at two wastewater treatment plants serving the city of Oslo (Bekkelaget wastewater treatment plant and VEAS wastewater treatment plant). Bekkelaget wwtp will be described in detail. For VEAS wastewater treatment plant a brief description will be given.

1.2 Wastewater treatment requirements for the Inner Oslofjord area

The Norwegian wastewater treatment legislation is harmonized with the EU-requirements as outlined in in the Urban wastewater directive (European Commission, 1991). Municipal wastewater from the City of Oslo are discharged to the Inner Oslofjord from two wastewater treatment plants (Table 1and Table 2)

Table 1.Treatment requirements for Bekkelaget wastewater treatment plant

Design capacity:	270,000 pe
Process	Mechanical, chemical and biological treatment steps, including nitrogen removal (pre-denitrification) and additional filtering of wastewater before it is discharged at - 50 m depth in the Oslofjord.
Treatment requirements	N-removal: 70 % (annual average)
	Tot-P-removal: 90 %(annual average)
	The treatment requirements include discharges via 2 storm water overflow weirs close to the wastewater treatment plant (Gamle rist and Kvaerner overflow weirs)
	The annual discharge of tot-N and tot-P via the two storm water overflow weirs, shall not exceed 2 % of the annual tot-N and tot-P load to the plant

1.2.1 Table 2.Treatment requirement for VEAS wastewater treatment plant

Design capacity:	650,000 pe
Process	Chemical precipitation and biological treatment in biofilm reactors (BIOFOR®) with nitrogen removal (post-denitrification) Separate stormwater treatment plant (ACTIFLO®) for use at high flow situations during rain and snow melt
Treatment requirements	N-removal: 70 % (annual average)
	Tot-P-removal: 90 %(annual average)

Both treatment plants have implemented process modifications that are in use during high influent flows.

1.3 Process modifications during high flow situations

A general extension of all treatment steps in the plant to make it possible to meet the stringent discharge requirements during all flow situations is very costly. An alternative to this strategy will be to introduce a process configuration that easily can be changed during high flow events. During normal flow, the total flow to the plant undergoes the standard treatment scheme for the plant.

During high flow events, the standard treatment scheme is changed, and a part of the flow to the plant undergoes an alternative treatment (in these two cases; chemical precipitation).

Chemical precipitation (coagulation + flocculation) has two main effects on the wastewater:

- Precipitation of soluble substances, primarily phosphorus

- Coagulation of colloids and small particles resulting in removal of organic matter, phosphorus, heavy metals, organic micropollutants and hygienic parameters (e.g. E-Coli). Normally, more than 90 % removal of total suspended solids (TSS) and total phosphorus can be expected. According to Norwegian experiences, approximately 70 % of the organic matter in undiluted municipal wastewater will be colloids and small particles . Consequently a removal rate of 70- 80 % for organic matter can be expected for chemical precipitation (Ødegaard, 1999)

During high flows, the incoming wastewater is diluted and such high removal rates as for undiluted wastewater will not be attainable. However the removal rates are significant and represent a big improvement compared to discharge of untreated wastewater to receiving waters via storm water overflow weirs.

Figures 1 and 2 show standard and modified treatment schemes for Bekkelaget WWTP and VEAS WWTP.

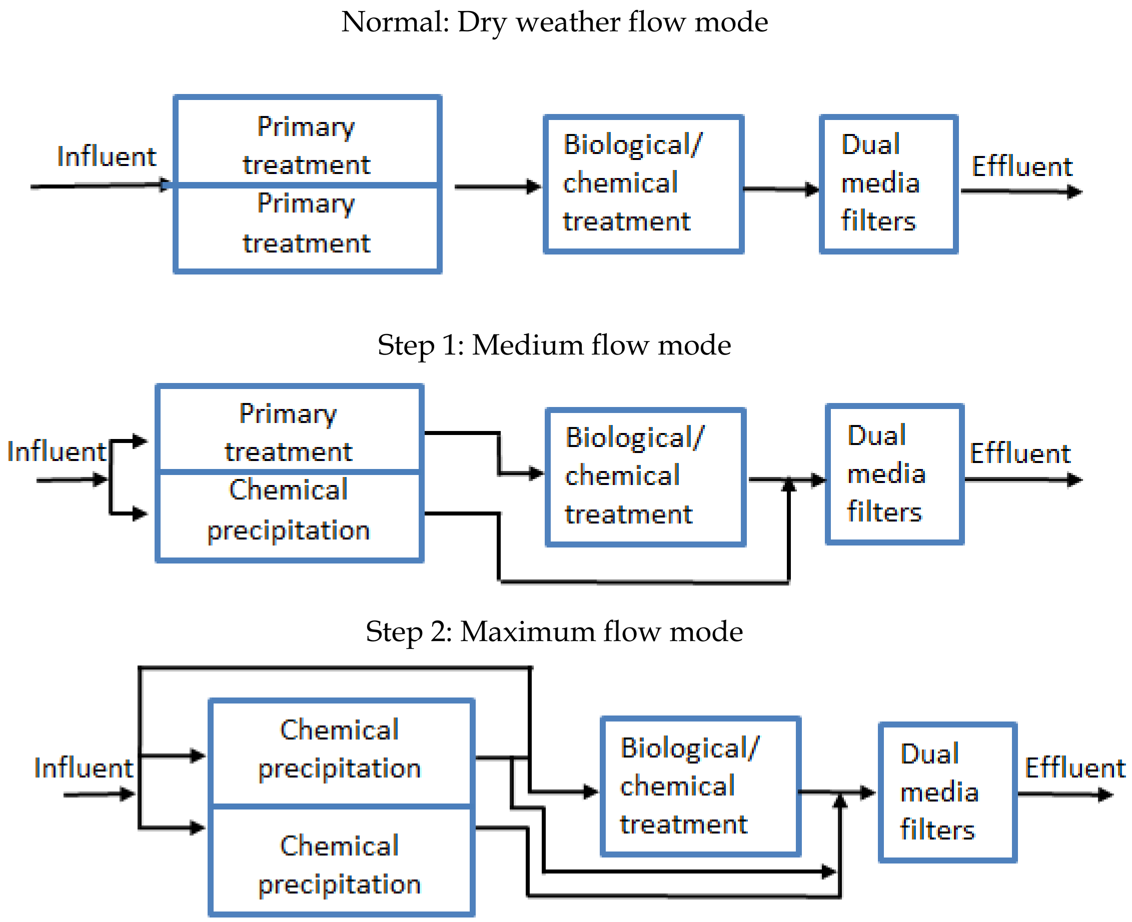


Figure 1. Standard and modified flow scheme for Bekkelaget WWTP

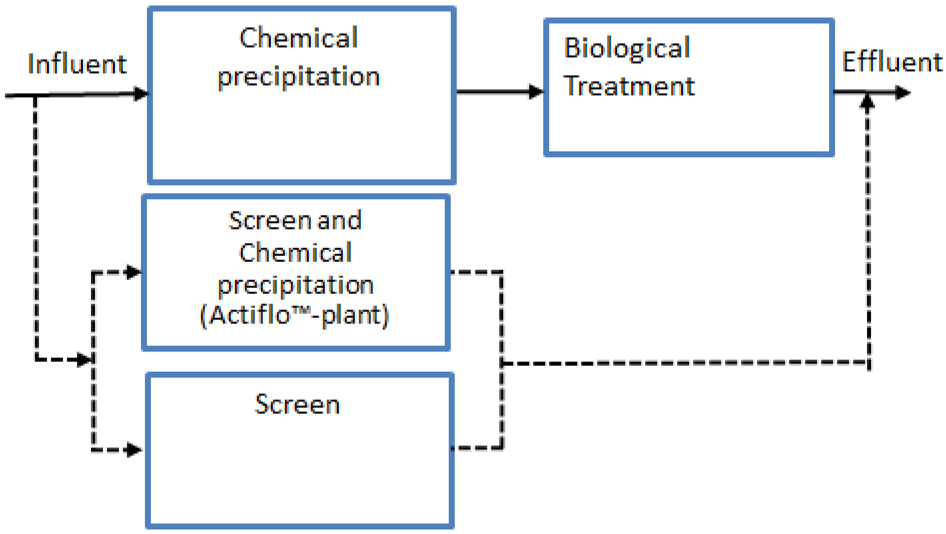
Normally the flow to Bekkelaget WWTP goes via bar screens and aerated grit removal chambers to primary settling tanks. The wastewater then enters the biological treatment step for nitrogen and phosphorous removal (simultaneous precipitation), and finally dual media filtration before discharge to the Oslofjord.

During high flows, the the function of the primary settling tanks will be changed to chemical precipitation (coagulation and flocculation) in two steps.

Step 1: Four of totally eight primary settling tanks are operated with chemical precipitation. The chemical treatment consists of dosing of prepolymerized aluminium salt (PAX-18) and a polymer as flocculant. The effluent from the primary settling tanks with chemical precipitation is bypassed the biological treatment step and directed to the dual media filters.

Step 2: If the flow to the plant continues to increase, the second half of the primary settling tanks are also operated with chemical precipitation. One part of the incoming wastewater is guided directly to the biological treatment step. At maximum flow to the plant, approximately 50 % of the flow will undergo chemical precipitation and 50 % of the flow will undergo biological chemical treatment (simultaneous precipitation with ferrous salts) and nitrogen removal.

Flow < 7,0 m³/s



Flow > 7,0 m³/s

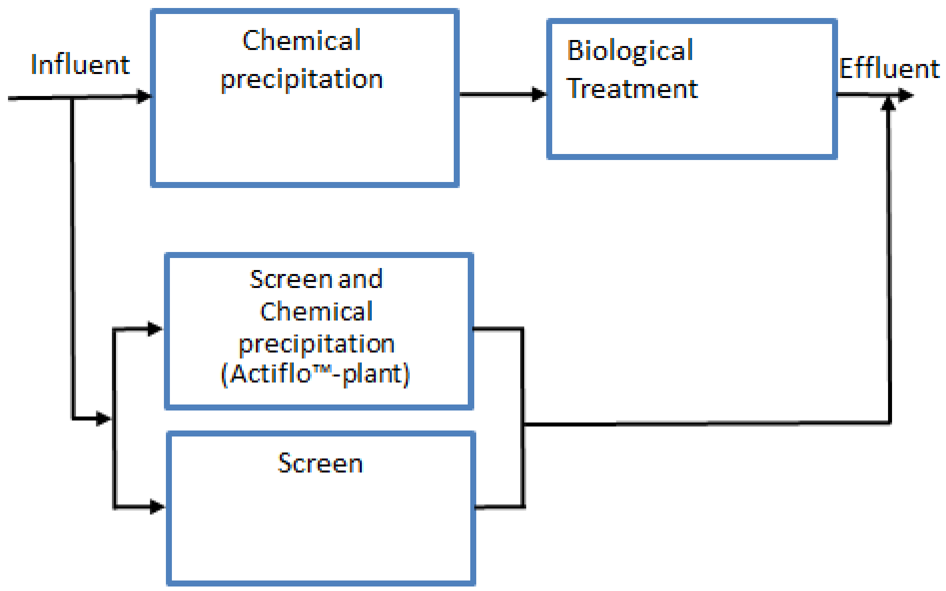


Figure 2. Standard and modified flow scheme for VEAS WWTP

During flows < 7,0 m^3/s to the VEAS WWTP, the wastewater enters the treatment plant via screens and aerated grit removal chambers. In the chemical treatment step, a prepolymerized aluminium salt and a polymer are added. The particles are removed in deep (12 m) settling tanks. Then the chemically treated wastewater enters the nitrification reactors (BIOFOR®) and finally the denitrification reactors (BIOFOR®). During flows < 7 m^3/s, a separate "stormwater treatment plant" is in standby mode. The stormwater treatment plant consists of two flow trains. One train with screen and a Actiflo™ compact chemical treatment plant and one flow train with a screen. When the flow to VEAS WWTP exceeds 7,0 m^3/s , the stormwater treatment plant is started automatically. The capacity of the flow train with the Actiflo™ treatment plant is 2,0 m^3/s. The capacity of the screen is also 2.0 m^3/s. Totally, the stormwater treatment plant has a capacity of 4,0 m^3/s.

1.4 Experiences from VEAS WWTP's stormwater treatment plant

The stormwater treatment plant at VEAS WWTP was put in operation in late 2008. The first full operational year was 2009. Figure 3 shows annual flows to VEAS WWTP, discharges via storm water overflow weirs and annual flows treated in the stormwater treatment plant for the years 2008 – 2012.

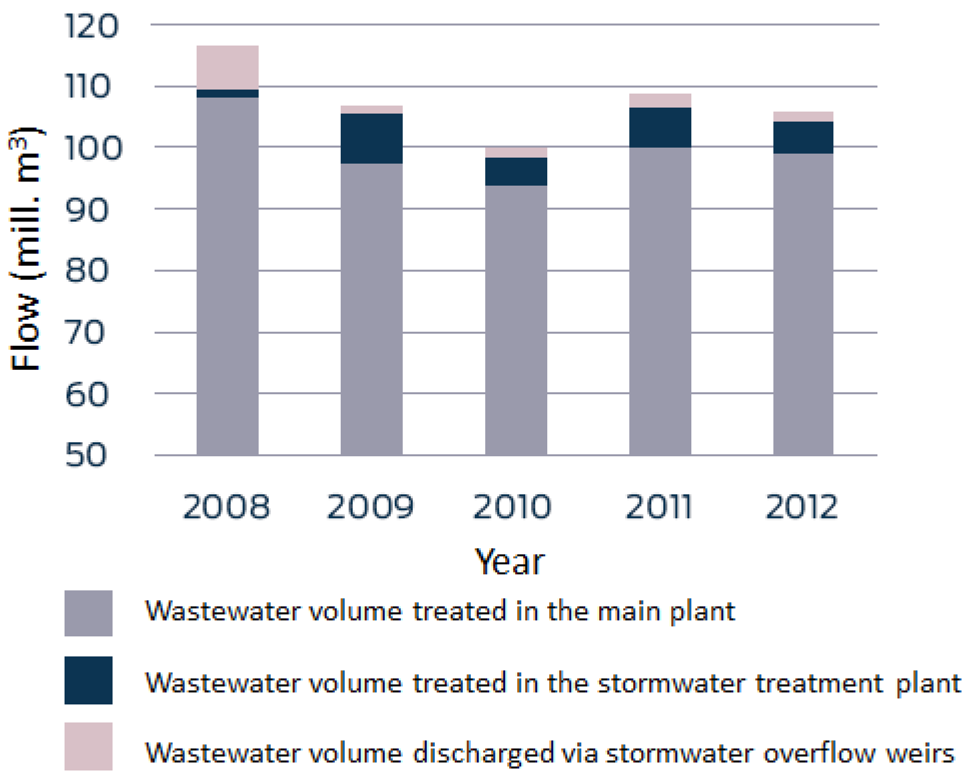


Figure 3. Annual flows to VEAS WWTP, treated wastewater volume in rain water treatment plant and discharges via storm water overflow weirs (VEAS, 2013)

The stormwater treatment plant has significantly reduced the annual CSO's from the VEAS's tunnel system. As an average for the years 2006 – 2008, 5,9 mill m^3 was discharged via 3 storm water overflow weirs in the VEAS's tunnel system. For the years 2009 – 2012 the average is 1,3 mill m^3, a reduction of 79 %. In 2012, the flow to the stormwater treatment plant was 5.61 mill m^3, 4.22 mill m^3 was treated in the Actiflo™ process line and 1.39 mill m^3 was discharged after screening.

1.5 General remarks

The two process modification schemes presented in Figure 1and Figure 2 illustrate strategies that are based on an increase of the treatment plants capacity after a change in the normal process trains. It is fundamental that the change in process mode are rapid and in accordance with the

inflow to the plant. Normally the change of process mode is included in the plants control system.
Chemical precipitation has a high capacity for removal of both soluble phosphorus (PO_4), total phosphorus (tot-P) and other pollutants in the particulate state. Nitrogen has a low removal rate (approximately 20 – 30 %) due to the fact that most of the nitrogen in incoming wastewater consists of soluble nitrogen components (NH_4). During high flow situations the treatment plant will perform with lower removal rates than during normal flow conditions. However, the discharges of pollutants via storm water overflow weirs are significantly reduced.
The discharge requirements for tot-P and tot-N at Bekkelaget and VEAS WWTPs are based on annual averages for removal rates. That means that a lower removal rate during high flow conditions will be compensated by a higher removal rate during dry and normal flow conditions.

2 Bekkelaget watewater treatment plant

2.1 General

The Bekkelaget WWTP is located approximately 3 kilometres south of the city centre of Oslo. The plant treats wastewater from about 290,000 person equivalents (pe) living in the eastern and south eastern parts of Oslo, and the plant has an average daily flow of 100,000 m^3/d and a maximum capacity of 260,000 m^3/d.

The plant is overloaded because it is designed for 270,000 pe, and the city of Oslo has started the planning process for an extension of the plant to a capacity of 490,000 pe.

The plant is built in rock caverns, except for storage tanks for chemicals and biogas. The total area of the caverns is 40,000m^2.

The effluent from the plant is discharged to the Oslofjord, which is a threshold fjord with low water replacement.

Oslo municipality owns the treatment plant and Bekkelaget Water Inc. (BEVAS) handles the operation on contract.

Figure 4 shows the overall schematic of the wastewater treatment at Bekkelaget WWTP. The figure does not show other aspects of the plant, i.e. anaerobic digesters and other sludge treatment units.

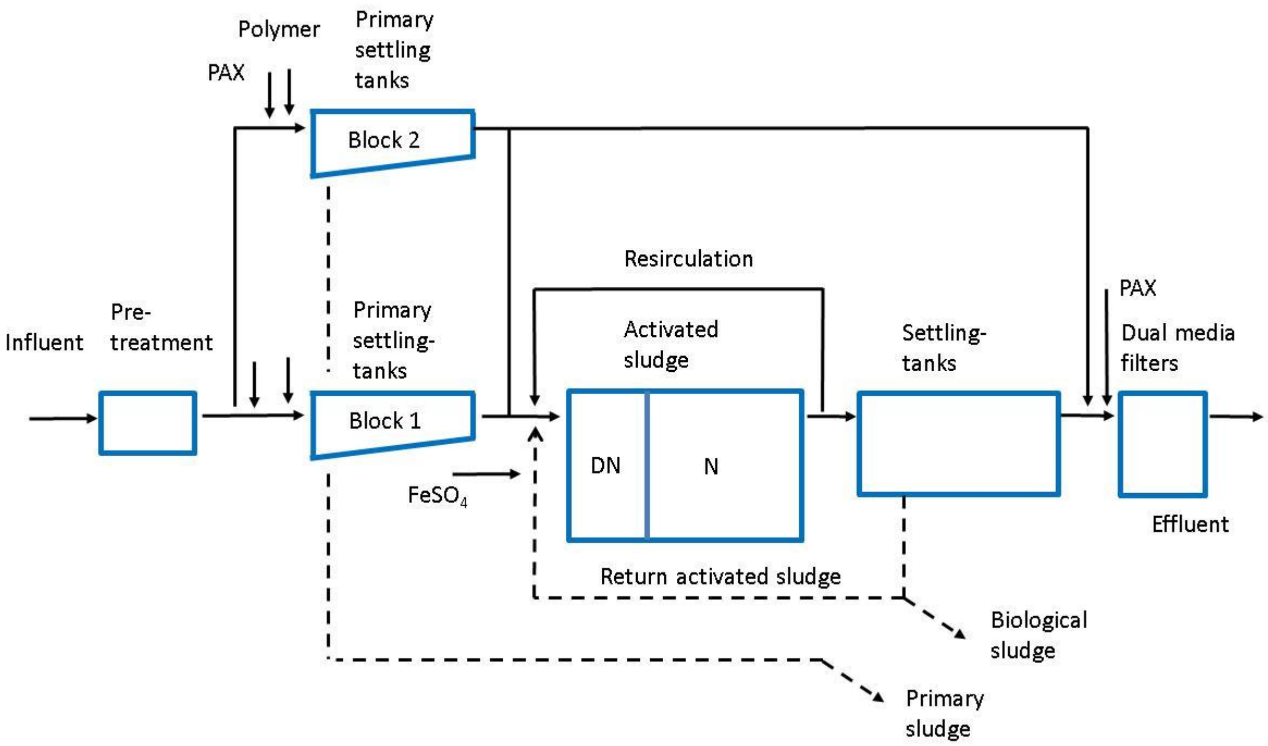


Figure 4. Simplified flow sheet for wastewater treatment at Bekkelaget WWTP

The incoming wastewater enters through the Kvaerner tunnel. The wastewater is lifted by screw pumps to the screens and the grit chamber. After grit removal the flow is split into two blocs (Block 1 and Block 2) of primary settling-tanks.

After primary settling the wastewater enters the denitrification zone in the activated sludge plant. Ferrous sulphate is added to the return activated sludge for phosphorus removal (simultaneous precipitation). After biological treatment, the wastewater is clarified in secondary clarifiers. Dual media filters are used as a polishing step before the treated effluent is discharged to the Oslofjord. PAX can be added before the dual media filters. More detailed information about the treatment steps are presented in Table 3

Table 3. Dimensions and capacities of key units at the Bekkelaget wastewater treatment plant

Unit description	Number of units	Specifications	Dimensions/capacity
Influent pump capacity	3		1.5 m^3/s
MEVA step screens, 3 mm opening	3		1.5 m^3/s
MEVA step screens, 2 mm opening	1		1.2 m^3/s
Sand and grease removal	4		225 m^3
Primary settling (0-2 m^3/s)	4		1,510 m^3
	4	surface area	375 m^2
Direct precipitation (2-4 m^3/s) with PAX -18	4		1,080 m^3
	4	surface area	270 m^2
Activated sludge process with biological nitrogen removal and simultaneous precipitation of phosphorus (ferrous sulphate dosing to return activated sludge)		Water depth	14 m
		Total volume (activated sludge volume)	77,000 m^3
	4	Anoxic	7,500 m^3
	4	Anoxic or aerobic	2,250 m^3
	4	Aerobic	9,500 m^3
Secondary sedimentation basin	4		7,800 m^3
	4	surface area	1,300 m^2
Return Activated Sludge (RAS)	4		650-1,300 m^3/h
Two-media sand filters (1.2 m light expanded clay aggregate “leca” and 0.6 m sand)	16	surface area	50 m^2
Effluent pump	3		1.5 m^3/s

Bekkelaget WWTP has two anaerobic digesters, operated in the thermophilic mode. The gas from the anaerobic digesters is upgraded to biomethane that are used as fuel for public buses in the City of Oslo. Digested sludge is dewatered by centrifuges and spread on farm land in the Oslo-region.

2.2 Modes of operation

The treatment processes shown in Figure 4 have 3 modes of operation, depending on the influent flow (Q) to the plant.

Mode 1: Dry weather flow mode $Q < 1.9\ m^3/s$
Mode 2: Medium flow mode $1.9\ m^3/s < Q < 3.0\ m^3/s$
Mode 3: Maximum flow mode $3.0\ m^3/s < Q < 4.0\ m^3/s$

The three operational modes are shown in figures 5, 6 and 7.

Operational mode 1: Dry weather flow mode ($Q < 1.9\ m^3/s$)

For a flows less than 1,9 m^3/s, all incoming wastewater undergoes mechanical and biological/ chemical treatment. The incoming flow is split between the two primary settling tank blocks for mechanical treatment. The effluent from the primary settling tanks is mixed with return activated sludge and added ferrous sulphate ($FeSO_4$) before the denitrification zone. Consequently nitrogen and phosphorus will be removed in the biological treatment step. Effluent from the secondary settling tanks will finally pass the dual media filters. Depending of the activated sludge settling properties and the total suspended solids (TSS) concentration in the effluent from the secondary settling tanks, poly-aluminium chloride (PAX) will be added to improve the removal of TSS and phosphorus in the dual media filters.

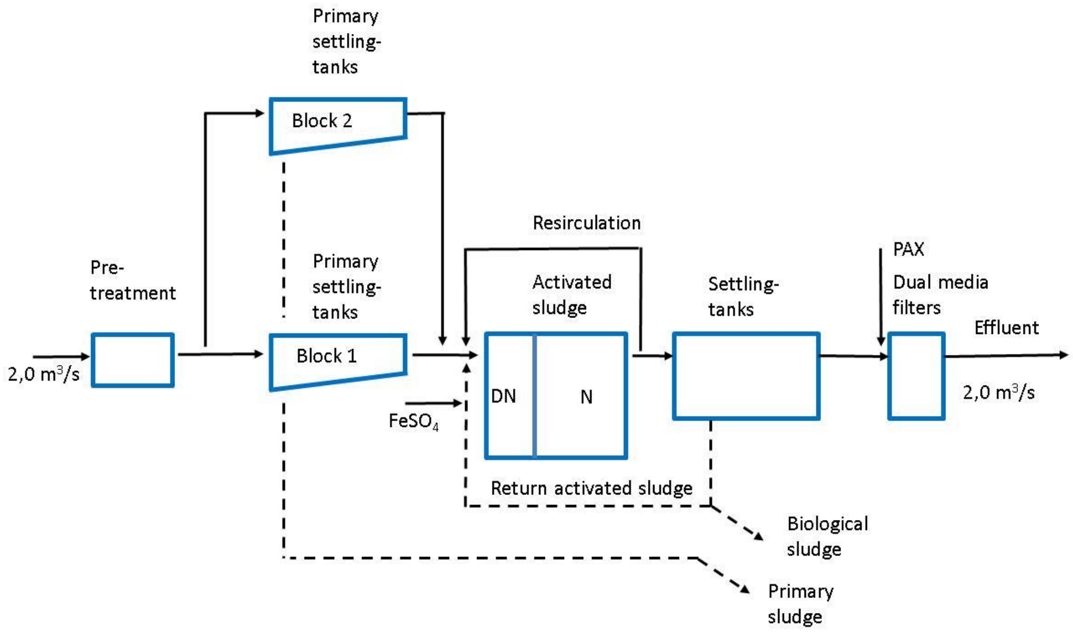


Figure 5. Operational mode 1, Dry weather flow mode ($Q<1.9\ m^3/s$)

Operational mode 2: Medium flow mode ($1.9\ m^3/s < Q < 3.0\ m^3/s$)

In this operational mode the influent flow will be split between the two blocs of primary settling tanks. All primary settling tanks have a 2 step flocculation unit with propeller flocculators and equipment for dosing of coagulants and polymer as a flocculant. In this operational mode one part of the wastewater undergoes biological/chemical treatment as described in Figure 6. The second part of the incoming wastewater will only undergo chemical treatment.

At the maximum flow (3.0 m^3/s) in this operational mode 1.7-1.9 m^3/s will undergo mechanical +biological/chemical treatment and 1.1-1.3 m^3/s will undergo chemical treatment. PAX is used as a coagulant and apolymer is used as a flocculant.

Effluent from the secondary settling tanks (mechanical, biological and chemically treated wastewater) and the flow from the primary settling tanks with chemical addition (chemically treated wastewater) are mixed prior to the dual media filters and the two mixed wastewater streams will pass the dual media filters. Incoming flow of 3.0 m^3/s is the maximum design flow for Bekkelaget WWTP.

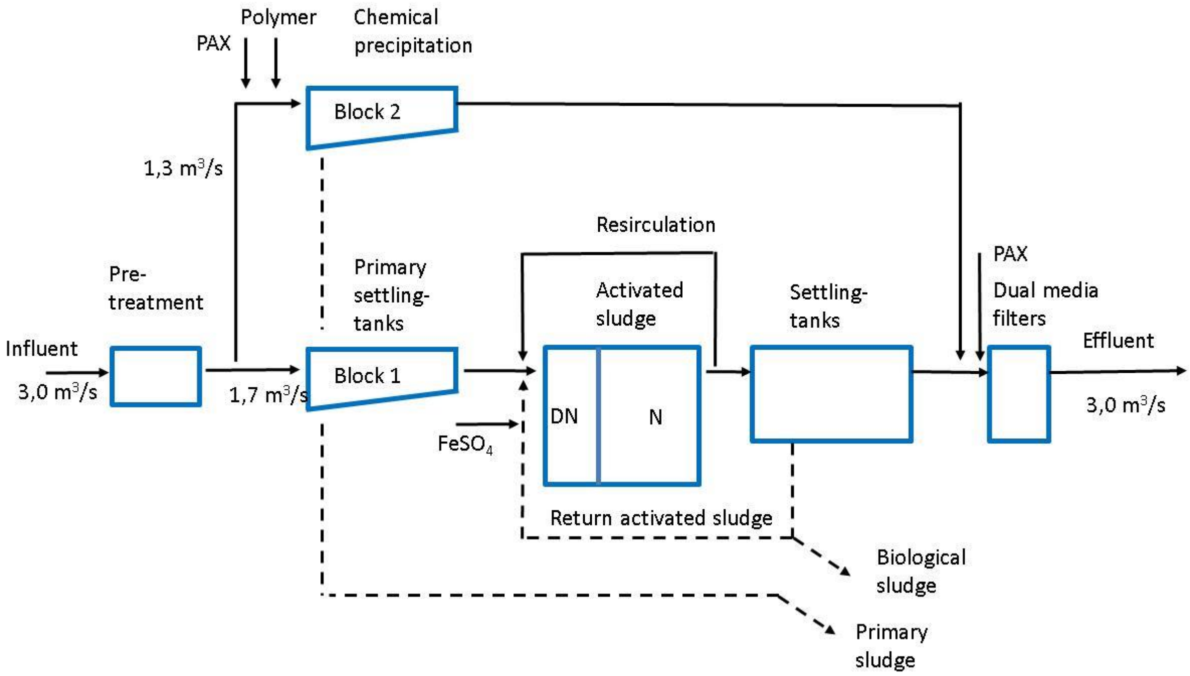


Figure 6. Operational mode 2, Medium flow mode (2.0 m^3/s <Q<3.0m^3/s)

<u>Operational mode 3: Maximum flow mode (3.0 m^3/s < Q < 4.0 m^3/s)</u>

As a consequence of the overload situation for the plant, especially during heavy rainfalls and snow melting, a third operational mode (Maximum flow mode) has been implemented. This operational mode is shown in Figure 7.

At flows larger than 3.0 m^3/s, primary settling tank block 1 and 2 will have chemical precipitation. At maximum flow (4.0 m^3/s) 1.3 m^3/s will be directed to primary settling tank block 2 and 1.7 m^3/s will be directed to primary settling tank block 1. In addition 1.0 m^3/s of influent pretreated wastewater will be bypassed directly to the biological treatment step.

A part of the effluent from primary settling tank block 1 (chemically treated) is bypassed the biological treatment step and mixed with effluent from primary settling tank block 2 (chemically treated). At a maximum flow of 4.0 m³/s, the mixed stream will be 2.0 m³/s. A maximum of 1 m³/s of the mixed stream are bypassed the dual media filters, not to exceed the design capacity of the filters.

The effluent from the secondary (biological) settling tanks (2.0 m³/s) and mixed effluent from primary settling tank 1 and 2 (totally 3.0 m³/s) passes the dual media filters.

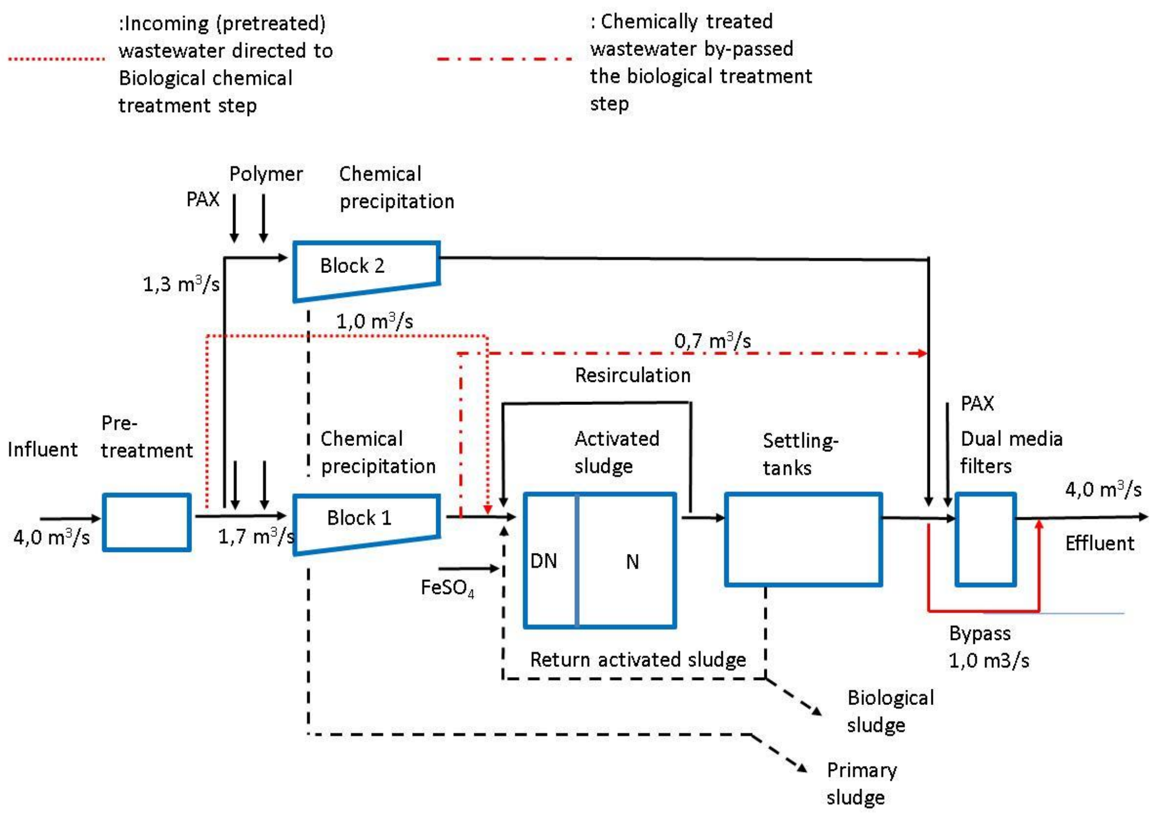


Figure 7.Operational mode 3, Maximum flow mode (3.0 m³/s < Q < 4.0 m³/s

Practical experiences show that the maximum flow that can be handled in this operational mode is a little less than 4.0 m³/s, normally 3.6 – 3.8 m³/s. This is due to some hydraulic limitations of the channels in the treatment plant.

3 Process changes

3.1 Change from "Dry weather" flow mode to "Medium flow" mode

The wastewater flow into the treatment plant depends on the wastewater level (the volume of stored wastewater) in the tunnel ahead of the treatment plant. In Dry weather flow mode the regulating gate at the inlet to the plant regulates the inflow to maximum 1,9 m^3/s.

When the flow increases, the regulating gate keeps a constant flow of 1.9 m^3/s according to signal from a flowmeter. If the flow continues to increase, the wastewater level in the tunnel will reach the predefined level for change to Medium flow mode. This level is normally in the range of 7.0 to 8.0 m, normally 7.5 m.

At a level of approximately 0.5 m below the level for changing to Medium flow mode (this is adjustable, the operators have to take different operational parameters into account), dosing of PAX and polymer start in the primary settling tanks, block 2

When the level of change to "Medium flow" mode is reached, a gate in the channel after primary settling tanks block 2 change position, and the chemically treated wastewater is passed to the channel ahead of the dual media filters. This can be seen on Figure *5* and Figure *6*.

3.2 Change from "Medium flow" mode to "Maximum flow" mode

When the mode of operation is changed to "Medium flow mode, the regulating gate at the inlet to the plant regulates the flow to 2.4 m^3/s. If the flow and wastewater level continue to increase in the tunnel ahead of the plant, the gate will regulate the flow up to 3.0 m^3/s. This will be the maximum flow in "Medium flow" mode, and the maximum level in the tunnel is normally 9.0 m

If the wastewater level in the tunnel continues to increase over the maximum level for "Medium flow" mode, a predefined level increase, normally 0.8 m, will take place before the dosing of PAX and polymer start up in the primary settling tanks, block 1

Dosing of chemicals to blocks 1&2 will go on for 25 minutes (predefined) before the flow will be increased to min flow (3.2 m^3/s) for "Maximum flow" mode.

The flow is allowed to increase until max flow (4.0 m^3/s) for "Maximum flow" mode is reached. The max flow is adjustable and normally 3.8 m^3/s is used (see Figure 7).

At a maximum wastewater level of 10 m in the tunnel , and a maximum flow of 4.0 m^3/s, the regulating gates for a stormwater overflow weir ahead of the plant will start to open. The gate will open for a minimum overflow of 1.5 m^3/s.

When the level of wastewater gradually decreases, the modes of operation gradually goes back to "Dry weather" flow mode.

4 General remarks concerning the process changes at Bekkelaget WWTP

The main goal of the operation of the Bekkelaget WWTP is to minimize the discharges via storm-water overflow weirs to the Oslofjord. Currently two overflow weirs are close connected to the influent side of the treatment plant and several other storm water overflow weirs are located in the combined sewer network of the central part of the city. The city of Oslo will during the first half of 2014 put in operation a new sewerage system covering the sentral and south eastern part of the city named Midgardsormen. The system includes a combined 2 km long transfer tunnel and storm water retention volume. The effective retention volume in the new transfer tunnel is 75.000 m^3. Combined with the existing inlet tunnel (The Kvaerner/tunnel) of 30.000 m^3, the total stormwater retention volume will be 105.000 m^3. This will drastically reduce the number of storm water overflow weirs in the sewerage network of the central south eastern part of Oslo city, as well as the annual discharge volume via storm water overflow weirs. The existing two stormwater overflow weirs connected to the inlet tunnel will be closed.

The new wastewater tunnel (Midgardsormen) is equipped with a sieving plant. In situations when the total storage volume is filled up and the wastewater treatment plant operates at maximum capacity, overflow from the tunnel system will be treated in the sieving plant before it is discharged at a depth of 50 m in the Oslofjord.

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