DEVELOPMENT OF WASTEWATER TREATMENT IN POLAND FROM PERSPECTIVE OF PRACTICAL IMPLEMENTATION

Jerzy Kurbiel

Cracow University of Technology, Institute of Water Supply and Environmental Protection, ul. Warszawska 24, 31-155 Kraków, Poland

SUMMARY

In 1990-96 a significant increase in number of wastewater treatment plants constructed occurred in Poland. The percentage of treated municipal wastewater had increased during this period from 60 to 81.2. By the end of 1996, among the others there were 123 high-effective wastewater treatment plants constructed with enhanced nutrient removal. The most widespread treatment technology was integrated biological removal of nitrogen and phosphorus in multi-stage reactors, often with chemical precipitation and generation of volatile fatty acids (VFA.) Sludge treatment usually included aerobic digestion at small plants, and anaerobic digestion and mechanical dewatering at larger plants.

KEY WORDS

wastewater treatment plants, wastewater treatment in Poland, mechanical treatment, biological reactors, wastewater sludge

INTRODUCTION

Poland is a country with population of 39,6 mill. About 62,6% of population live in the cities and 37,4% in rural areas. Over 16.5 mill. persons are served by wastewater treatment plants, what translates into 66,4% of municipal and 4.1% of rural population. After the period of stagnation, in 1992 an intense development in construction of wastewater treatment plants occurred. The major rationale for that progress became more stringent effluent standards introduced with the directive of the Ministry of Environmental Protection, Natural Resources and Forestry (MEPNRF) on November 5, 1991. The most important requirement in the directive was introduction of high-effective removal of nitrogen and phosphorus. The directive introduced new water protection strategy where for the first time effluent standards were tied to wastewater treatment scope and required efficiency. The resolutions in the directive have simplified designing and execution of necessary treatment efficiency. It was in contrary to the regulations from before November 1991 regarding river water quality, which were often abstractive and were freely interpreted as a base for designing wastewater treatment plants. The requirement of nutrient removal introduced by the new directive was important factor for development of wastewater treatment technologies and in particular it demanded critical examination of so called “conventional biological treatment”. There was demand for development and implementation of high-effective technologies, where unit processes are more meaningful for high and reliable quality of effluent than in conventional methods. The most important rationale for development of high-effective treatment technologies at highly-automated and mechanized plants in Poland were as follow:

- reduction of barriers for transfer and exchange of technological expertise, even long before the 1990 transformation, what had prepared wastewater treatment in Poland for utilization of other countries' experience;

- rapid development in manufacturing of mechanical equipment and automation systems as well as in monitoring and process control worldwide;
- establishment of local governments, what resulted in local initiatives for wastewater treatment plant constructions;
- introduction of new public bidding law, which specified clear rules for bids for designing and equipment supply for wastewater treatment plants; bids are based on market rules and enable selection of the best and the cheapest option;
- creation in late 1980s of ecological funds which were separated from the state budget and which are major source of financing for construction of wastewater treatment plants in municipal and in rural areas.

WASTEWATER TREATMENT IN POLAND

Table 1. Wastewater treatment in Poland

Wastewater	Total						From cities					
	bill. m^3/a			%			bill. m^3/a			%		
	1990	1995	1996	1990	1995	1996	1990	1995	1996	1990	1995	1996
Requiring treatment	4,11	3,02	2,91	100	100	100	2,31	1,85	2,56	100	100	100
Treated including:	2,77	2,32	2,30	67,4	76,8	79	1,39	1,25	2,08	60,2	67,6	81,2
primary	1,46	0,92	0,90	35,5	30,5	31,0	0,55	0,25	0,75	23,8	13,5	29,3
chemical	0,21	0,19	0,18	5,1	6,3	6,1	0	0,04	0,17	0	2,2	6,6
biological	1,10	1,13	1,1	26,8	40,1	} 41,9	0,84	0,96	1,04	36,4	51,9	} 45,3
w/enhanced N/P removal	-	0,08	0,13	-	-		-	-	0,12	-	-	
Untreated	1,34	0,70	0,61	32,2	23,2	21	0,92	0,60	0,48	39,8	32,4	18,8

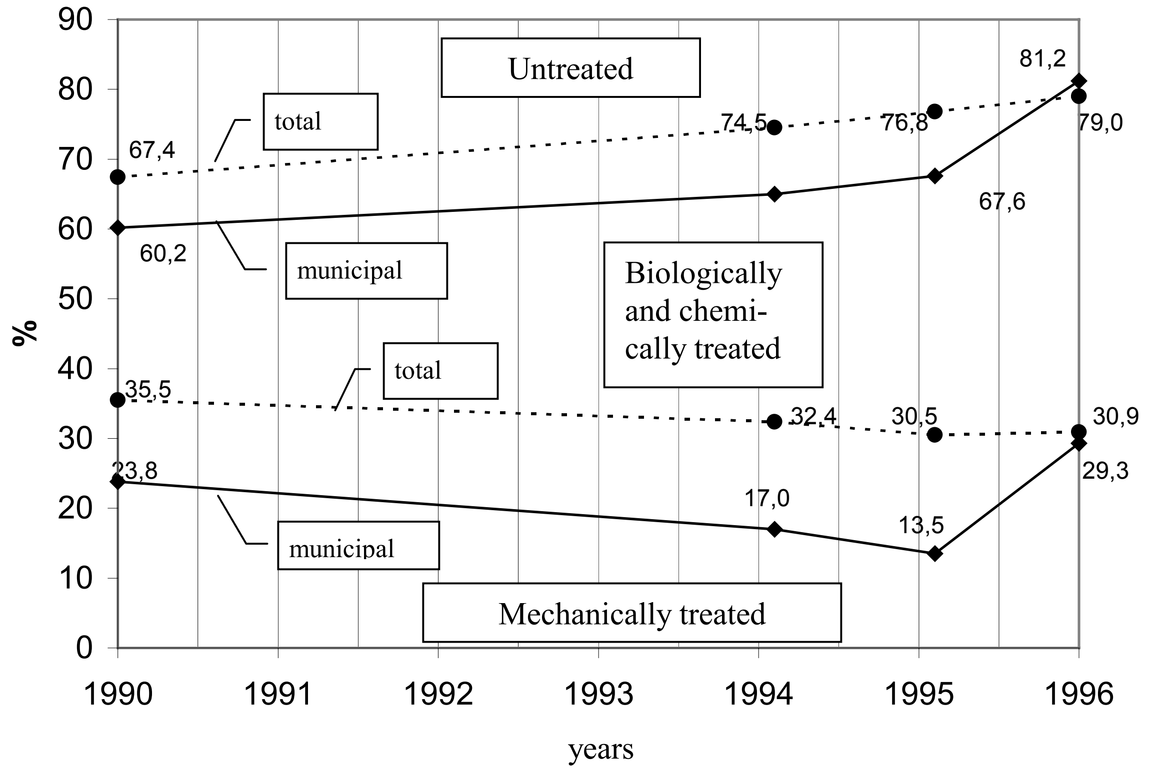
Table 2. Number and capacity of municipal wastewater treatment plants at the end of 1996.

Type of plant	**Number**	**incl. with Q_1 > 1000 m^3/d**	**total capacity, thous. m^3/d**
1. Mechanical	179	85	1195
2. Chemical	10	4	205
3. Biological	1159	358	4859
4. W/enhanced N and P removal	123	73	916
Total	1471	520	7175 (2.62 bill. m^3/a)

Table 3. Population served by wastewater treatment plants in 1996.

Total in mill.	**% of population**	**Biol.-chemical plants**	**% of population**
16,5 (incl. rural areas 0,6)	66,4 (incl. rural areas 4.1)	10,9 mill.	45,7
Note: in 48.3 % of rural households wastewater is directed to septic tanks.			

Fig. 1 Wastewater treatment in Poland in 1990-96 in %



New statistical data regarding wastewater treatment and discharge in Poland in 1996 is published in the State Office of Statistics' (GUS) report (Warsaw, 1997.) The 1996 data is presented in table 1 and compared to 1990 and 1995 data.

Table 2 contains the number and total capacity of municipal treatment plants according to data gathered at the end of 1996. In the following table 3 the population served by wastewater treatment plants in 1996 is showed.

The data presented in the above tables permits the following inference:

- During the period of six years analyzed in the tables total volume of wastewater requiring treatment decreased by 29%; volume of municipal wastewater at first decreased as compared to 1990, and then slightly increased by about 10%. It was due to smaller drinking water consumption and water conservation, and scaled down industrial production directly after 1990. The latter trend is gradually reversing now.
- During the analyzed period the total volume of treated municipal wastewater sharply increased, especially in 1995-96. There was 2.08 bill. m^3 of municipal wastewater treated in 1996, what made 81.2% of all wastewater requiring treatment. The most significant is increase in the volume of biologically treated wastewater—0.2 bill. m^3 during the last year.
- Total of 1.16 bill. m^3 of wastewater was biologically treated in 1996, including 0.12 bill. m^3 of wastewater treated with enhanced nitrogen and phosphorus removal technologies. It makes 45.3% of all municipal wastewater requiring treatment.

- Significant increase in mechanical and chemical treatment of wastewater can be seen, too (respectively 29.3% and 6.6% of all municipal wastewater requiring treatment.) It is mostly due to step-by-step running in of high-effective wastewater treatment plants, i.e. starting-up operation of primary treatment part of a plant with pre-sedimentation and sometimes also with chemical pre-precipitation. Examples may include large wastewater treatment plants in Wrocław, Gdańsk (chemical precipitation) and Poznań.
- At the end of 1996 the percentage of untreated wastewater was 21%, including 18.8% of municipal wastewater.
- According to table 2, for total of 1471 plants there are 1159 of biological plants, including 358 large and medium ones (Q>1000 m^3/d.) There are 123 wastewater treatment plants with enhanced N and P removal of total capacity 916 000 m^3/d in Poland. Those are usually medium- and large-size plants.
- Biological and biological/chemical plants serve a population of 10.9 mill. what makes 45.7% of total population served by wastewater treatment plants.
- Wastewater from 48.3% of rural households is discharged into septic tanks.

The numbers presented in table 1 do not show the whole picture of the progress in wastewater treatment plants construction as they relate to new plants only. Extension and renovation of existing conventional biological wastewater treatment plants is going on in recent years with a goal to increase their treatment efficiency. The statistics do not include such projects.

When analyzing 42 large cities (pop.>100,000), one can see that 5 of them do not have any wastewater treatment plants at all and 10 of them have plants with primary treatment only. The following voivodship cities do not have plants:

- Warsaw (left bank)	-	pop. 1,143,400
- Łódź (1 line for 100,000 m^3/d operating)	-	838,400
- Bydgoszcz	-	383,600
- Nowa Huta (quarter of Kraków, under construction)		221,000
- Toruń (under construction)	-	291,800
- Zielona Góra (under construction)		
- Szczecin-Pomorzany (designed)		

Only primary treatment plants operate in:

- Poznań (biological stage under construction)	-	582,900
- Wrocław (biological stage under construction)	-	640,700

During recent years the following plants implemented chemical precipitation:

- Kraków-Płaszów	-	523,900
- Gdańsk-Wschód	-	361,700
- Wrocław	-	640,700

There are many wastewater treatment plants under construction in large cities, but their investment cycle is longer than for medium-size plants.

DIRECTIONS IN IMPLEMENTATION OF WASTEWATER TREATMENT TECHNOLOGY IN POLAND

Primary treatment
Screens

Present directions in application of screens in Poland is installation of fine screens 6-10 mm at the plants with primary sedimentation or screens 2-3 mm if no primary sedimentation exist instead of medium screens used in the past.

In the situation when wastewater is pumped before fine screens the experience shows that it is justified to install coarse screen 40-100 mm in order to protect the pumps from plugging or damages which may be caused by larger impurities.

In screen construction there is a trend to move away from screens with mechanical chain scrapers and extension arm scrapers. Modern constructions include stepped screens and drum screens with mechanical devices for continuous or intermittent scraping. Stainless steel screens are used. The best are methods that combine scraping and transport of screenings with their dewatering and pressing, and optionally flushing with water, and next with their transport to enclosed containers. Screens and screening transport system almost always operates automatically controlled with wastewater level sensors before the screen or with time switches.

Grit chambers

There is a trend to use two different types of grit chambers:

a) **Grit chambers aerated** with compressed air with horizontal screw-like movement of particles. This type of grit chambers usually incorporates fat-removal function. The grit removal efficiency is high, however their application is limited by the size of the plant and the technological processes which can be used in further treatment stages. Such grit chambers are not recommended in case when a plant has biological reactors equipped with anaerobic chamber for biological phosphorus removal and does not have primary sedimentation.

b) **Circular grit chambers** that are used at smaller plants; **aerated circular grit chambers** used at medium-size plants.

Important component of a grit chamber is sand removal and separation system. Sand trapped in gutters is transported with air lift or rotary pumps. The water is separated from sand in separators. Domestic implementations showed that the most effective are rotary separators with screw sand transportation that are manufactured in Poland.

Primary settlers

There is a trend to decrease lower-bound limit of primary settlers' application. In 1970s following example of some European countries even large plants did not use primary sedimentation. Now it is recommended to use primary sedimentation for capacities from 5000 m^3/d. A rationale for using primary sedimentation is the following:

- Operational optimization, energy and cost savings. Removal of about 30% of BOD_5 load in primary settlers makes that the required reactor volume is smaller by similar percentage, and produces significant energy savings due to smaller air demand in reactor.
- Introduction of pre-fermentation (hydrolysis) of wastewater—a new reliability factor important for N and P removal—what is possibly only in designs with primary settlers.
- Abandoning of primary sedimentation usually means aerobic sludge digestion. Experience shows that aerobically digested sludge has worse dewatering properties and it causes problems with its ultimate utilization. On contrary, anaerobically digested sludge, what is indispensable at plants with primary sedimentation, produces biogas and has good dewatering properties.

Biological treatment
Activated sludge

Modern biological reactors with activated sludge equipped with automatic process control, increased process kinetic rates and high biomass concentration enable removal of pollutants in a process which is faster, broader, more efficient, and carried on in integrated way with increased volumetric efficiency. Optimum technology, which meets all effluent requirements regarding nitrogen and phosphorus, is based on single-sludge, multistage activated sludge system, where a sequence of aerobic/anaerobic conditions enables high-effective biological removal of nutrients, nitrogen and phosphorus.

Multistage biological reactors with activated sludge used in Poland for integrated removal of carbon, nitrogen and phosphorus can be classified according to flow characteristic into two groups:

- with continuous flow
- with cyclic operation (SBR and its modifications)

A. Continuous flow multistage biological reactors with activated sludge

Multistage reactors, which development was inspired by *J. Barnard's* patent in 1970s have been for many years constructed in developed countries. For last five years they are being designed and constructed in Poland, too. The system that is the most often used in Poland is a three-stage system developed by *Barnard*, **"Bardenpho,"** with the modification: additional anoxic chamber for pre-denitrification of return sludge.

Continuous flow biological multistage reactors with different hydraulic configuration and of various construction are used at different size plants: from small ones with capacity of 500 m^3/d to the largest ones. The process of surplus phosphorus accumulation by microorganisms, which occurs in such reactors, carries on in two stages in a sequence of anaerobic and aerobic conditions.

In Poland surplus phosphorus accumulation under alternating anaerobic/aerobic conditions is implemented in biological reactors with different level of process integration, with or without coexisting nitrogen removal. At some places, usually older plants or plants after modernization of conventional activated sludge system, there are two-stage reactors for nitrification and denitrification with chemical phosphorus precipitation.

A system that is based on two-stage biological reactor, named **Phoredox**, and then renamed **A/O**, used for high-effective biological removal of phosphorus and carbon without nitrogen removal, has been implemented in Koszalin and Łódź during the first stage of the plant constructions. Average phosphorus removal efficiency at the plant in Łódź in July 1998 was 88.5% (average effluent concentration 0.7 gP/m^3.) Average efficiency of BOD_5 removal was 96% (effluent concentration 7.6 g/m^3.) Phoredox reactors with extended aerobic zone retention time are sometimes used for biological phosphorus removal and nitrification, if due to low total nitrogen concentration in raw wastewater, no denitrification is needed.

Another modification of the three-stage system is **system UCT** implemented at several plants (e.g., Połaniec, Nowy Sącz.)

Further development of Bardenpho technology in Poland and worldwide goes into direction of increasing readily biodegradable organic carbon concentration in influent wastewater to a level which allows for intensification of biological denitrification and phosphorus removal. Some promising results have been achieved in Poland with use of pre-fermentation of primary sludge (also called hydrolysis) to transform organic material contained in the sludge into readily biodegradable compounds, mostly VFA, which can be easily assimilated by the biomass. The most effective way to carry on the process is to use special tanks called fermenters that are coupled with primary settlers and sludge thickeners (Nowy Sącz). Pre-fermentation may be also carried on in thickeners themselves operated under special regime and coupled with primary settlers (Jasło, Dębica, Zamość, Złotów) or exclusively in fermenters (Jaworzno).

At the wastewater treatment plant in Zamość, which was constructed and optimized according to the presented above technology, high treatment efficiency was achieved in winter and summer 1997. Effluent concentrations for 50% probability level were as follow: BOD_5 – 5 g/m^3, N-NH_4 – 0.66 g/m^3, TN – 6.0 g/m^3 and TP – 0.4 g/m^3.

Pre-fermentation targeted at VFA generation is an important factor that increases reliability of biological nitrogen and phosphorus removal in newly constructed wastewater treatment plants in Poland. It applies especially to those plants which have unfavorable raw wastewater composition.

Continuous flow multistage reactors in Poland operate with one of the following flow patterns:

- plug flow,
- cascade flow with complete mixing in each stage (chamber)
- circulating flow with zoning within a single chamber
- cascade-circulating (circulation within each chamber; each chamber is a separate zone)
- alternate cycling through two chambers with different conditions.

These reactors coupled with final clarifiers are used in Polaand at both, large and small wastewater treatment plants.

B. Cyclic multistage reactors with activated sludge (SBR)

Unlike in the reactors discussed earlier, in cyclic reactors wastewater inflow and outflow, or sometimes only outflow is intermittent with use of one, usually two or more reactors.

First cyclic reactors known as oxidation ditches aerated with brush rotors were implemented in Poland in 1961. Development of new generation of cyclic reactors that were capable of integrated nutrient removal at smaller plants occurred after 1992. During recent years such reactors have been used at larger plants, too (>5000 m^3/d). There is a number of design offices and construction companies which implement cyclic reactors of different size, construction and with different technological modifications. The largest SBR plant is a one in Nowy Targ (24,000 m^3/d with partial aerobic digestion), and then in Chełm Lubelski (20,000 m^3/d with primary settlers and anaerobic digestion.)

Small cyclic reactors are commonly used at small rural wastewater treatment plants. However, their weak points are frequent failures of decanters used for extraction of treated wastewater.

All newly constructed plants are equipped with up-to-date process monitoring and computer control (PCL). Control systems offered by foreign firms (Nowy Targ, Jasło) can become a model for solutions developed by Polish companies. Good examples of Polish monitoring and control systems are at wastewater treatment plants in Jaworzno and Zamość.

Biofilters

Reactors with fixed biomass (biofilters with solid filling in form of packets or loose plastic profiles) offer less possibilities in regard to biological nutrient removal. Primary, as the biomas is fixed to biofilter’s filling it is not possible to integrate all processes in one biofilter like in the reactors with activated sludge. Polish operational experience shows that two-stage biofilter system with recirculation: 1^o- anaerobic contact bed, denitryfying, 2^o- aerobic trickling filter, nitryfying is a good solution.

Application of biofilters in new technological systems and with modern plastic filling systems is still on time for small wastewater treatment plants. Also, in case of existing, medium size plants equipped with older-type biofilters the modernization is more cost-effective than replacing the biofilters with alternative solutions what often happens.

While removal efficiency for biofilters is only slightly lower as compared to that of activated sludge systems their operational costs are low and operation is very simple.
Nowadays two types of plants with biofilters, both usually prefabricated, are used:

- **Trickling filters**, where wastewater flows from the top to the bottom through porous biofilter's filling. Such biofilters at low loads can remove not only BOD_5 but also sustain nitrification.
- **Contact beds**, where the filling in form of packets or loose plastic profiles is submerged in wastewater. Loose filling is suspended by wastewater flow from the bottom to the top. Contact beds may be aerated, and then the removal efficiency is similar to that obtained at trickling filters (removal of BOD_5 and possible nitrification), or non-aerated, and then they can sustain denitrification. Contact bed used for denitrification in 1st stage reduces nitrates contained in recirculation from 2nd stage (aerated) utilizing organic carbon contained in primary effluent.

When as a criteria biofilter surface organic load or biomass surface organic load is applied the biofilters can be classified as: low-loaded (nitrifying, 2 g BOD_5/m^2d), medium-loaded (4 g BOD_5/m^2) and high-loaded (pre-treating). In order to achieve required biofilter hydraulic load and required concentrations in influent wastewater recirculation is used.

In recent years in modernized biofilters new types of plastic packet fillings (PE or PP) of large specific surface–100-200 m^2/m^3 are used, what enables high volumetric yield of a biofilter. In Poland packet fillings EK, Terrapak, 2H – FKP, BIOPAC and loose fillings – Bado i Palla are used. Self-supported height of the filling layer can reach even 6.0 m. Introduction of plastic fillings permits construction of light biofilter casings made of steel and significant increase in biofilter's surface load, and consequently hydraulic load.

Phosphorus removal in systems with biofilters is carried on through chemical precipitation in humus tanks.

Hybrid systems for biological wastewater treatment

Hybrid biological technologies with coexisting suspended and fixed biomass are being introduced in Poland in recent years. This type of reactors include **contact beds** (aerated and non-aerated) discussed earlier and **moving beds**.

Hybrid system enable operation of reactors with high biomass concentration and high process kinetic rates due to increased external and internal diffusion in biomass fixed to large surface of the filling.

The following presents characteristics of the hybrid methods:

- temperature variations have low impact on the treatment process; increased process kinetic rates;
- required volume of biological reactors is small;
- amount of biomass flushed-out of the reactor is small;
- biomass concentration in reactor can be easily increased;
- aerated with compressed air, (natural aeration can not be used);
- high cost of the filling;
- high removal efficiency of suspended solids in primary treatment is required.

Hybrid reactors with stationary contact bed aerated with compressed air are used at small plants. They usually consist of packet fillings with aeration grate underneath. There are several examples of such applications with stationary contact bed and mechanical aeration in Europe (mainly in Scandinavia) and in Poland. One of them is SEBIOFIKON. Biological reactor made of polymal resin and reinforced with glass fiber is filled with coils of propylene net. Inside there are transverse partitions forcing labyrinth flow. After the last transverse there is sedimentation chamber without any filling.

Sludge processing

In sludge processing implementations closed anaerobic digestion chambers with biogas utilization, which were given up in 1980s, are becoming more and more popular again (e.g., Dębica, Zamość, Jasło, Nowy Sącz, Ostrowiec Świętokrzyski). However there is still a number of low-effective and environmentally noxious open, non-heated anaerobic digestion chambers—usually remnants from previous construction stages (Jaworzno, Piła).

Sludge dewatering in newly constructed plants usually is carried on in belt presses or centrifuges. Based on the operational experience the following conclusions can be formulated:

- the method of sludge digestion significantly affects final thickening and dewatering effect
- industrial pollution in municipal wastewater has adverse effect on sludge processing efficiency
- sludge dewatering effect in drum-screen devices is worse than guaranteed, especially when wastewater has composition different from typical municipal wastewater.

CONCLUSIONS

1. A dynamic growth in construction of wastewater treatment plants in Poland in 1990s could be observed, especially in regard to municipal wastewater treatment plants (Fig.1). In recent years the attention was focused on small- and medium-size plants with short investment cycles, not exceeding 2-3 years. There is a number of high-effective plants under construction in large cities of population over 100,000. However still large percentage of produced wastewater is not treated (20%). At many older plants treatment efficiency is unsatisfactory; there is much delay in wastewater management in rural settlements.

2. Dominant technology applied in Poland in construction of wastewater treatment plants is treatment with activated sludge in multistage biological reactors with integrated removal of carbon, nitrogen and phosphorus, and sometimes supported with chemical precipitation. Large- and medium-size plants use mainly three-stage reactors Bardenpho or UCT. At small-size plants cyclic reactors, like SBR and its modifications, are being more and more popular.

3. In regard to biofilters there is a trend to use modern plastic filling of large specific surface in designing of new small plants and in modernization of older ones. One- and two-stage systems are designed. The latter with denitryfying contact bed.

4. implementations of sludge processing and its ultimate utilization methods are delayed in comparison to wastewater treatment technology. At new large- and medium-size wastewater treatment plants dominant technology is anaerobic digestion in digestion chambers. Small plants prefer aerobic digestion. Mechanical sludge dewatering is getting more and more popular.

5. Operational experience shows that the high effective technologies implemented in Poland meet the expectations.