ATHENS – AN OLYMPIAN CHALLENGE

Gwion Kennard
Atkins Water
Atkins Consultants Ltd
Longcross Court, 47 Newport Road, Cardiff
Wales
gwion.kennard@atkinsglobal.com

Costas Ripis
EYDAP
Laodikias 29 & Ilision 9
157 71 Zografou, Athens
Greece
ripis@otenet.gr

INTRODUCTION

Project Background

EYDAP, the Water and Sewerage Corporation of Athens, was required to determine how the XXVIII Olympiad would affect its ability to meet the required levels of service for its water supply and wastewater networks in the city centre and its nearby regions. As part of its Olympic Games preparations, EYDAP commissioned Atkins Consultants Ltd to provide expert assistance within these engineering disciplines.

Since the summer of 2000, Atkins Water has been providing specialist expertise to EYDAP to help address the significant water demand, water supply and sewerage issues associated with staging an event of the order of the Olympic Games.

This paper is based on the work undertaken as part of the commission to deal with the sewerage element of the project.

Sewerage Study Objectives

The principal objectives for the sewerage study were as follows:

- To develop a hydraulic model (within an internationally renowned software package) that encompasses all of the core sewers (trunk sewers) with sufficient complexity to be suitable for identifying major hydraulic deficiencies during the Olympic Games in August 2004.
- To identify outline options for alleviating the known deficiencies.
- To develop a model suitable for further future development and use as a planning tool.

In 1997, EYDAP published its Athens 'Master Plan for the Sewerage Division' and this was used as a prime source of information for the study, along with the many other studies commissioned by EYDAP and the ministry of public works.

The hydraulic model would be a skeletal representation of the Athens sewerage system. Further work will be required should the model need to be used as a full Drainage Area Planning (DAP) tool.

Due to the time constraints of the project and the available funding it was agreed that the model should target five core areas including the following:

1) Development of the Olympic Village and the impact on the downstream sewers.
2) The Olympic Stadium and surrounding developments.
3) The Athens City Center and 'core sewer network' including the Kappa Alpha Alpha (KAA) Trunk sewer.

4) The Fallirikon Sports Complex along the coastal region of Athens.

5) The impact of sewage from cruise liners docking at Pireaus harbour.

Flooding experienced in 2002 in central Athens and the propsect of hosting the 2004 Olympic games added significant political impetus to the resolution of the sewerage network problems.

Catchment description

Athens has a residential population of approximately 3,850,000 (within the existing sewerage model) covering a total area of around 41,000 hectares. The Athens drainage catchment includes a variety of geographical areas ranging from mountainous slopes to coastal beaches. The city is protected by a ring of mountains creating a geological 'basin' or 'bowl'. This feature has led to constraining the spread of development and has resulted in high population densities in the older areas of the city. The topography surrounding the coastal lowlands is generally steep with the coastal strip varying between 2 to 15km in width. The coastal stip extends up to the Kifissos and Ilissos river valleys. Refer to Figure 1 for a thematic representation of the 'Athens bowl'.

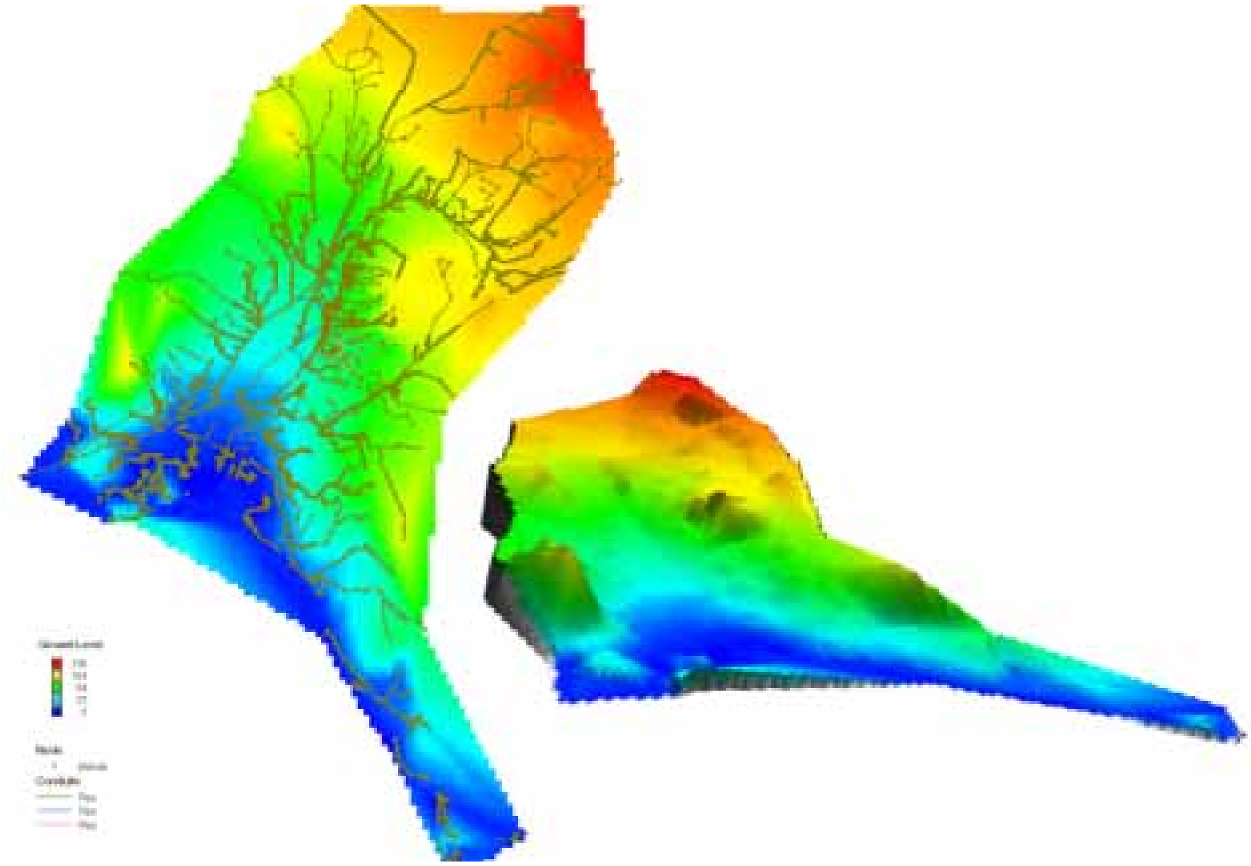

Figure 1 – 3D Thematic Plan of Athens

Land use includes residential, commercial and industrial areas with several locations comprising heavy industries including railway engineering works, steel works and manufacturing. The majority of the largest heavy industrial sites are located to the west of Athens and are not included in the digitised sewerage network.

Catchment Sewerage System

Historically the sewerage system within the drainage area was developed as a number of distinct systems. Over the years, the smaller sewerage systems have amalgamated which has resulted in a network with very deep sewers and a large number of bifurcations. The coastal sewerage system has also been developed in this fashion over many decades and this has resulted in a number of pumping stations constructed ‘in series’ along the seafront.

The expansion of the city has resulted in an extensive system of sewerage pipework of varying diameters, shapes, depths and materials. The catchment is predominantly drained by separate foul and surface water systems, with the only truly combined area located towards the east of the main KAA trunk sewer. The combined area is one of the oldest and most densely populated regions within the Athens catchment and has suffered badly over the years with historical flooding.

The pumping stations located along the coastal region are integral to the sewerage network with flows pumped from the low lying land along the seafront into the coastal interceptor. These flows are in turn conveyed to the treatment works and ultimate disposal.

Historical Development of the Sewerage System

The high density development coupled with the steep catchment gradients has given rise to a number of problems within the catchment including high volumes of storm water runoff with short concentration times during storm events. These combined with capacity shortfalls in the storm and foul sewerage networks has resulted in significant flooding. However, there are benefits to the catchment topography notably that apart from the coastal interceptor, the sewerage system operates through gravity sewers thus having low operational and maintanence running costs.

METHODOLOGY

In order to meet the project objectives there were a number of significant challenges to face. To help overcome these the modelling was addressed in five sections of work.

1) Digitising of the Network

Prior to the study, there were no digital sewer records available for the Athens sewerage network.

In order to define what data to collect and the extent of the model digitisation, the foul sewers on engineering plans were marked up to cover the primary network (pipes of 500mm diameter and upwards).

Additional digitisation detail was undertaken within the Athens sewerage network where:

- Olympic developments are planned;
- known deficiencies exist; and
- where pumping stations, Combined Sewer Overflow’s (CSO’s) or penstocks are located.

The original aim of the digitisation process was to identify key nodes (manholes) to a maximum of 2000 nodes (this corresponds to 1500 persons per node on average, and around 30 ha/node overall).

Following further discussions between EYDAP and Atkins, it was agreed that a more comprehensive model could be prepared by digitising an estimated 5000 nodes.

The available record plans were used to input the following information:

- Manhole location;
- manhole referencing;
- manhole ground levels;

- conduit invert levels;
- conduit shape;
- conduit size (width and height); and
- conduit connectivity.

Within the Athens digitised network, there are a total of 30 CSOs and 31 pumping stations. Following discussions with EYDAP and due to the programme time constraints and the funding available, it was decided that the ancillaries would not be surveyed as part of the study.

EYDAP presented as built drawings and schematic diagrams for the majority of the pumping stations and CSOs however, in the absence of such data it as was necessary to make engineering assumptions based on experience.

2) Model Construction

Connectivity checks were undertaken on the network to ascertain whether the surface water system drained into the foul system at points in the catchment. The surface water system has been modelled in areas where it receives CSO spills, or connects to the foul system and there is known interaction.

Generally for the trunk sewers all manholes have been included however, a degree of simplification was undertaken on certain non-critical areas of the network. Where there were no Olympic developments, flooding, structural or operational issues, the plans of the network data were interrogated to establish whether inclusion of this data was deemed necessary.

The model statistics for the hydraulic computer model for the Athens catchment are noted in the following Table:

Foul Nodes (nr)	Storm Nodes (nr)	Foul Conduits (nr)	Storm Conduits (nr)	Foul Conduit Length (m)	Surface Conduit Length (m)	CSOs (nr)	Outfalls(nr)	Bifu'n (nr)
6,176	128	6,064	133	501,855	14,131	30	29	70

Table1 – Model Statistics

The new projection system used in Greece is a Transverse Mercator Projection (tm) with specific characteristics for the central meridian, the scale coefficient, reference latitude, and additional constant to X and to Y. This is based on the Geodetic System of Hellenic Geodetic Reference System of 1987 (EGSA '87) with reference to the ellipsoid system of GRS'80 (Geodetic Reference System 1980 - GRS'80) with specific principal characteristics.

The existing sewerage network plans were provided in an unfamiliar transformation system, based on a different ellipsoid (unfortunately not with the same parameters or parallel, as the GRS 80) called Bessel.

It was therefore necessary to re-coordinate the existing network so that it was in the correct geographical position according to the background maps.

Gross contributing areas contained within the model were defined automatically, viewing map backgrounds of the catchment in conjunction with the model sewer network.

Subcatchments were generated using an automated polyline tool and saved into tables in readiness for import to the modelling package.

The subcatchments have been based on Thiessen polygons generated from the manhole data and dividing a single polygon representing the entire catchment.

The final contributing subcatchments were adjusted using data from the Raster maps (Ortho maps, satellite imagery) to identify large green permeable areas and other non contributing areas. These areas were removed from the model for runoff purposes.

Percentage impermeability within each contributing area was determined using a sampling procedure. Assessments were made regarding illegal storm connections, cross connections and deterioration in the foul systems that may have occurred over time allowing the ingress of ground water.

For the Athens model, the **Large Catchment Routing Model** was considered the most applicable. For this, the flow routing coefficient depends on rainfall intensity, contributing area and surface slope. The software also applies a timestep lag and routing factor multipliers, that are functions of subcatchment area, ground slope and catchment length.

During historical calibration, reductions in the percentage impermeability in subcatchments were made taking into account factors such as: catchment slope, proximity to streams, proximity to other separate sub-catchments of similar age, information obtained from aerial photography, observations made during site inspections and good engineering judgement based on knowledge of the catchment acquired from numerous site visits that had been undertaken.

The **storage compensation** exercise undertaken accounted for storage potential available in the unmodelled sewer laterals and associated chambers. Unmodelled storage was incorporated into the network at sub-catchment nodes.

Where the storage algorithm calculated large amounts of unmodelled storage (considered unfeasible, mainly due to irregular subcatchment shape) the actual unmodelled storage incorporated into the model was altered using best engineering judgement on the basis of an assessment of the sub-catchment.

Population and Trade flow data is based on the Industrial/Professional and Public/Municipal/Other figures as derived in the 'Water Supply and Demand Assessment' section of the study.

The sewerage system in Athens is known to suffer from a number of historical problems associated with infiltration, illegal connections and cross connections. Some of the issues associated with stormwater entering the sewerage system include: lack of non return valves on the CSOs on the KAA, illegal connections on private properties of stormwater sewers to foul sewers, excessive infiltration of ground water, especially during rainfall and diversion of polluted stormwater low flows from the river system via flow diversion structures. These poorly maintained control facilities allow large volumes of flow to be diverted during rainfall events to the trunk sewers. Within the limits of time and data available, but with the invaluable knowledge of Operational staff, these defects have been considered during the optioneering process.

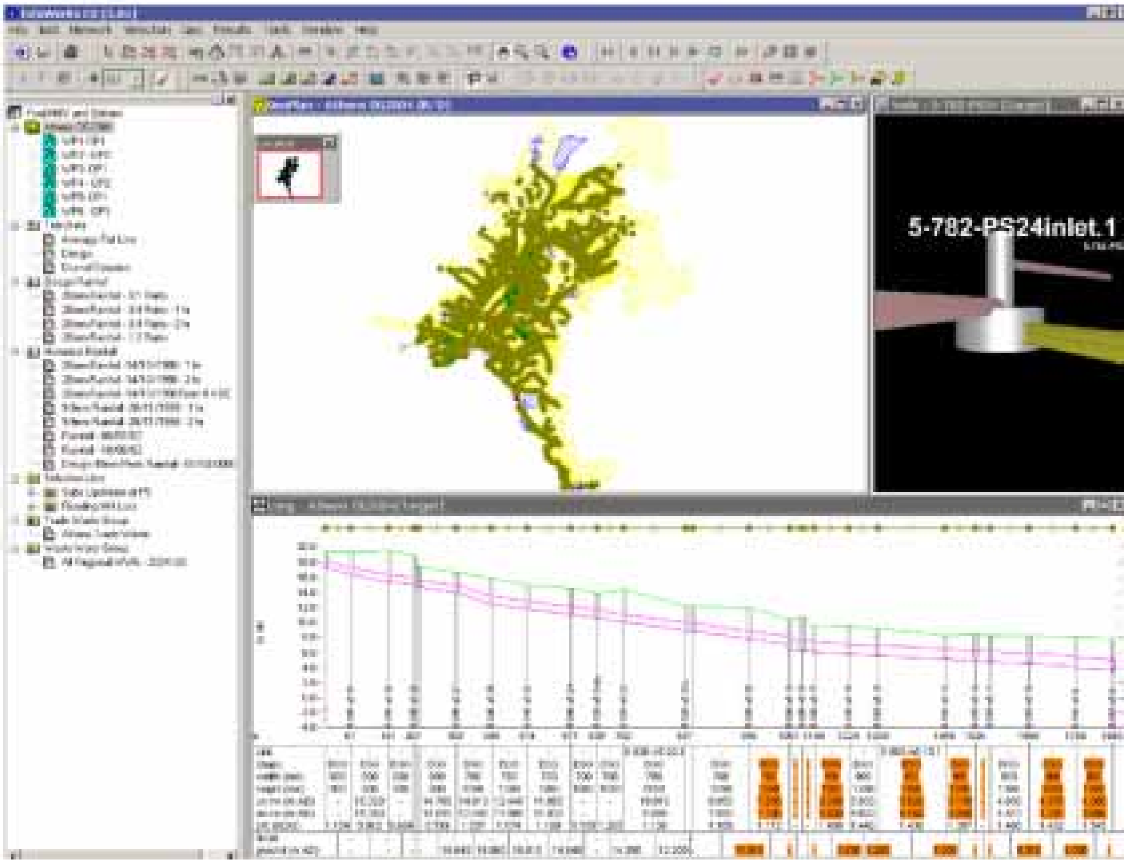

Figure 2 – Plan, 3D and Long Sections of Model

3) Model Calibration

The model has been calibrated as follows:

- Conducting Dry Weather Flow (DWF) calibration on the coastal region using the summer DWF data as obtained from the EYDAP telemetry.
- Undertaking DWF calibration on the remainder of model by checking that CSOs were not operational and that there were no flooding locations. Checking average daily totals arriving at Psyttalia Sewage Treatment Works (STW) for accuracy.
- Storm calibration for the coastal region using the EYDAP telemetry information.
- Performing historical storm calibration using EYDAP flooding records of the remainder of the model.

Prior to and after the calibration process, the stability of the model was tested using 10 year return period summer storms of various durations. Inspection of the ancillaries and at selected sections of the model found no evidence of any significant instability.

From the telemetry data provided by EYDAP, seven dry days (four winter and three summer) were selected in order to undertake the DWF calibration of the coastal region of the Athens catchment. The days were selected following consideration of the length of dry period prior to each day and of the number of operational telemetry sites at the pumping stations.

Having completed the calibration of the DWF for the coastal region, the remaining model was checked for CSO spillages and areas of flooding during dry conditions.

Once the initial DWF calibration was complete, it was then necessary to calibrate the model against actual historical flooding in the five core areas to conform the model was robust. Data was taken from 25 rainguage stations, analysed in order to assess the typical rainfall profile for Athens, and then used as reference data for the validation.

Historical rainfall events were chosen to be representative of summer rainfall of a severity that caused flooding of the sewerage network. Calibration events were chosen on the basis of duration, intensity, reliability of data and variation.

The model was run using the rainfall for the three selected storm events and the resulting predictions of the flow were compared to those observed during the actual event at each of the pumping stations. The simulations were all run for 24 hours duration irrespective of the event's actual duration since the pumping station data was in daily format.

Where significant differences were found between predicted and observed data, further investigation was carried out. The model was adjusted by re-assessing the previous estimates of percentage contributing area and making other minor amendments to the model. The model was refined by a process of continuing iteration until reasonable calibration plots were obtained for all pumping stations.

Calibration events included known flooding problems experienced at specific pumping stations, overflows operating at several coastal pumping stations during storm conditions, and regular surcharging of specific sewers.

It is considered that the 'existing' (pre Olympic Games) Athens model has been calibrated in accordance with the recommendations as outlined at the outset of the study. **The model is deemed suitable for its intended purpose,** namely, the hydraulic assessment of sewerage system performance within the scheme envelope. It is also considered that the model has been callibrated to enable the development of outline solutions for all the agreed targeted areas of the events.

4) Hydraulic Assessment

For the Olympic Games investigation work, the calibrated model was amended to reflect the future design horizon as follows:

- The ongoing sewerage rehabilitation scheme for the coastal region was incorporated.
- The ongoing sewerage collection system for Piraeus harbour area was included.
- The Games developments were included in the model.
- The new collector sewer for the Olympic Village was built into the existing model to assess the impact downstream.

All developments are assumed to contribute foul flow and a 5% allowance for storm flows (allowing for illegal connections and cross connections etc). Connections to the existing system have been assessed with reference to the local topography and in reference to the documentation as provided by EYDAP and ATHOC for the Olympic Venues.

Summer design storms of varying durations were generated using a **Synthetic Design Rainfall Generator**. The durations of the design event were considered to provide a reasonable estimation of the catchment critical durations for a sufficient variety of rainfall scenarios.

The design rainfall approach uses the adopted design rainfall parameters as supplied by EYDAP for the various Athens regions. The rainfall indices within the Athens options model have been adjusted to reflect the zones of influence of the design rainfall regions.

From a 60 minute, 1 in 10 year design rainfall event, locations were identified where the model predicts significant flooding >25m^3.

The model predicted hydraulic problems in the central Athens sewerage system, an area which includes a significant portion of combined sewerage. EYDAP confirmed these problems do exist, that there are known hydraulic deficiencies within the trunk sewer and that external flooding and high levels of surcharge are a regular problem. It was agreed that there are no known historical DWF problems associated with this area of the network.

Flooding during storm conditions in the coastal region of Athens is predicted in the 'existing' model and therefore cannot be attributable to the Olympic developments. The Olympic venues will however, exacerbate any existing hydraulic deficiencies by increasing pressures on the already overloaded sewerage system.

All of the identified deficiencies were taken forward to the optioneering stage.

5) Option Development (Optioneering)

In the optioneering stage, solutions were developed for all deficiencies identified during the hydraulic assessment. Options included individual schemes or a combination of schemes to form work packages. Solutions that were developed to solve all catchment deficiencies included:

- Provision of high level overflows.
- Offline storage tanks.
- Localised (small scale) storage.
- Increasing the capacity of the upstream overflows discharging the excess storm flows to the sea.
- Offline storage tanks and small amounts of upsizing.
- Fitting screening devices to retain aesthetically unsatisfactory solids within the sewerage network.
- Sealing of the offending manholes (although this option was later discounted, because pressurising the sewerage system causes flooding to occur in other locations).
- Storm relief sewers.
- Full separation of the sewerage systems.
- Providing a storm relief sewer and transferring flows to the KAA trunk sewers.

Following a prioritisation exercise, the suggested phasing of the proposed recommended work packages was presented.

SUMMARY

Prior to the study, there were no digital sewer records available for the Athens sewerage network.

It was determined that the hydraulic model to be constructed, would be a skeletal representation of the Athens sewerage system and further work will be required should the model need to be used as a full Drainage Area Planning (DAP) tool.

Generally, for the trunk sewers, all manholes have been included. However, due to the limited number of manholes to be digitised (5000), a small degree of simplification was undertaken on certain non-critical areas of the network. Where there were no Olympic developments, flooding, structural or operational issues, the plans of the network data were interrogated to establish whether inclusion of this data was deemed necessary.

The catchment is predominantly drained by separate foul and surface water systems, with the only truly combined area located towards the east of the main KAA trunk sewer. The combined area is one of the oldest and most densely populated regions within the Athens catchment and has suffered badly over the years with historical flooding.

The model predicted hydraulic problems in the central Athens sewerage system, an area which includes a significant portion of combined sewerage. EYDAP confirmed these problems do exist, that there are known hydraulic deficiencies within the trunk sewer and that external flooding and high levels of surcharge are a regular problem. It was agreed that there are no known historical DWF problems associated with this area of the network.

All of the identified deficiencies were taken forward to the optioneering stage. In the optioneering stage, solutions were developed for all deficiencies identified during the hydraulic assessment.