Flooding of polder areas that are dominated by greenhouse industry

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ABSTRACT

In 1998, severe rainfall-fed inundations of polders in the western part of the Netherlands have led to large economic losses, especially in polders with a high percentage of land occupied by greenhouses. In this study an integrated approach is used in order to find innovative solutions for this type of high-density development areas. In a case study of the Oranjepolder a model has been created which includes all important hydrodynamic and hydrological processes. This includes the rainfall runoff processes of greenhouses, individual greenhouse rainwater storage facilities and their discharges to the open water. Interactions between the surface water system and sewer system in the urban areas are included. Overland flow was added, to simulate flooding. The use of integrated modelling was essential to the identification of flooding problems in the Oranjepolder. Limitations are the large amount of data required for this model and the time it takes to run a calculation. The integrated approach used in the Oranjepolder has led to the identification of solutions for flood prevention that could not be identified in a traditional modelling approach.

KEYWORDS

Greenhouses, polders, hydrodynamic modelling, integrated, inundation

1 INTRODUCTION

In 1998, severe rainfall-fed inundations of polders in the western part of the Netherlands have led to large economic losses, especially in polders with a high percentage of land occupied by greenhouses. These polders are characterized by a high degree of imperviousness, thus fast rainfall runoff processes. Their low availability of water storage and high economic value makes them particularly vulnerable to flooding. Traditional solutions such as creating storage basins and widening of transport canals are not applicable, because available space is limited and acquisition of land for storage purposes is economically unfeasible. Clearly there is a need for solutions for this type of high-density development areas.

Previous approaches to study these densely built polder areas failed to deliver appropriate solutions because the high level of standardization in modelling could not capture important small-scale hydrological processes. The methodology is often standardized with a high level of simplification to make the computational process less data and time demanding. For instance, large areas (up to 30 hectares) of pervious and impervious surface were connected to channels in between culverts with a diameter of 1 meter, while in reality the discharge is spread over the length of a channel. This modelling approach resulted in extensive flooding which should be solved by enlarging the culverts around discharge locations and creating additional water storage at an available or affordable location. The solutions were not completely implemented due to political and economic objections.

In areas with little open water and high percentages of impervious surface, it can be essential to study the details. In areas with greenhouses, the individual rainwater storages at plot level have an important influence on the water balance of the polder. The storages are privately owned, therefore information on variations in available storage capacity is difficult to obtain and is not included in the standardised modelling approach. The scope of a water system study is often limited to the area and to the water system components that fall under the responsibilities of the organization conducting the study. Typically, water management responsibility in a polder area is divided between the surface water system, sewer system and greenhouse water systems. Planning, development and maintenance of the surface water system are executed by water boards, whereas municipalities focus on the management of the sewer system. Greenhouses and their water system and storage facilities are under private management. Due to this division in roles, problems arising from interactions between the different systems are often not taken into account. An integrated approach is essential to identify these interactions and find solutions for the system as a whole.

In this study an integrated approach is used to analyse rainfall-induced flooding in polder areas dominated by greenhouse industry. Important flow processes in the polder are identified and added to an integrated model. Varying levels of modelling detail are used; a high level of detail is used where this is required to correctly model and understand the causes of occurring inundation. Integrated modelling of sewer and surface water systems is especially important in polder areas, because differences between surface water levels and ground levels are small (typically 30 to 70 cm), so surface water and sewer system are likely to interact. The objective of this study was to investigate the possibility of integrated modelling of these areas, to find the benefits and the limitations of this methodology as a standard for future research.

2 METHODS

Study area. The Oranjepolder is a polder area in the western part of the Netherlands (51°57' N, 4°12' W). The total area is 490 hectares and contains the village Maasdijk (ca. 4000 inhabitants taking up 33 ha). The largest part of the polder 344 ha (70%) is filled with greenhouse industry and only 3.9% is reserved for open water. The rest of the polder is covered by a cemetery 0.3%, industrial grounds (5%), sport grounds (5%) and infrastructural and other areas taking up 16.9% (Oranjewoud, 2010). The surface level elevation in the Oranjepolder varies between 0.5 and 2.5 m NAP (MSL).

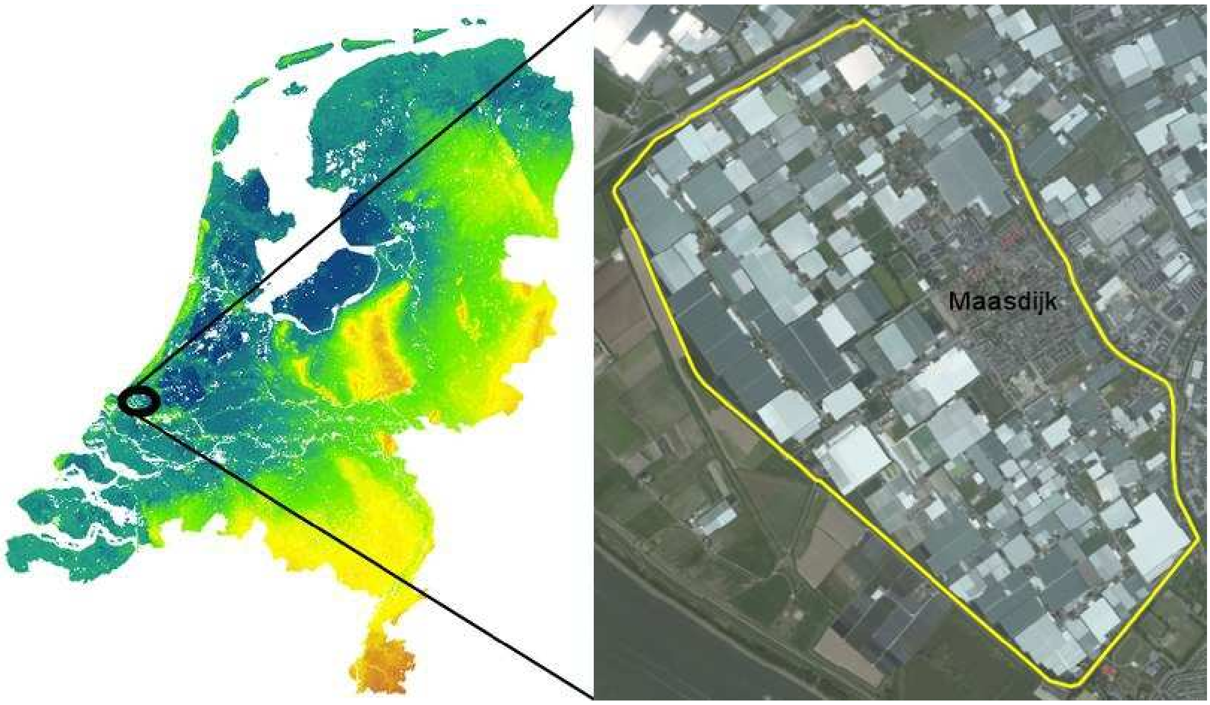

Figure 1: Study area Oranjepolder and the location in the Netherlands

The division between the Oranjepolder and the surrounding area is made by the Oranjedijk which separates the water systems. The polder is raised above surrounding waters which means that water is pumped into this area from a surrounding belt canal and water flows out under gravitational flow. Desired water levels are maintained by weirs.

The maintenance of the open water system is the responsibility of the water board of Delfland. The municipality Westland maintains and controls the sewer system in the village. Greenhouses are privately owned and operated by horticulture companies, with surface areas ranging from 1 to around 12 hectares. The greenhouse rainwater storage facilities are operated by the greenhouse owners; the discharge to the open water system is managed by the horticulturist. Water storage facilities at greenhouses range from 500 m^3/ha (which is the legal lowest limit) to almost 2500 m^3/ha.

Hydrodynamic model A hydrodynamic model was created in SOBEK (v2.12.002; Deltares, 2012), taking the most important hydrological and hydraulic processes into account: rainfall runoff, sewer system, channel flow and overland flow processes. After separately modelling all of these parts, a combination has been made resulting in one integrated model.

<u>Rainfall runoff</u> The rainfall runoff component represents dry weather flows and rainfall runoff processes for (un)paved areas and greenhouses. The total area of the Oranjepolder is split into these three categories (paved, unpaved and greenhouse) and modelled separately. The greenhouses are modelled individually with their corresponding water storage facilities. The water storages are filled with rainwater collected on the rooftops and is used for irrigating crops inside the greenhouses. To prevent water shortage during the dry periods in summer, when crop water demand is highest, the storages are kept as full as possible. After a dry period, a part of the storage facilities is empty, so rainfall from the greenhouse roofs is captured to fill the storage before excess water is discharged to the open water. The water usage fluctuation at greenhouses as found by Albers (2010) has been used, including evaporation from these facilities, while a distinction was made between different classes of greenhouses depending on their water usage. In this way the greenhouse surface area and available storage are modelled representing the actual discharge location and volumes to surface water.

Pervious areas in the Oranjepolder are mostly covered by grass and have corresponding evaporation characteristics. Seepage, infiltration and drainage towards channels through the soil are also included. Impervious areas are modelled as areas without infiltration.

<u>Sewer Flow</u> Impervious areas that are linked to the sewer system are represented in a sewer flow module. The combined sewer system, which transports both wastewater and storm water, is represented with dimensions of the actual sewers. All manholes, pumping facilities and spillways are used in this model. The model as it was created in 2007 is updated to the latest situation. A direct link is made between the sewer flow and channel flow models. The links between sewer and open water have an automatic non-return valve. In reality these valves have often functioned less than perfect. This means that a high water level in the channels could create a flow into the sewer system. The assumption is made in this study that the valves work properly.

<u>Channel Flow</u> The channels in the Oranjepolder are modelled with the dimensions as measured by the water board of Delfland. All hydraulic structures such as culverts and weirs are included in the model.

<u>Overland Flow</u> The Digital Elevation Model (DEM) for the Netherlands (AHN2 detail 0.5x0.5 m) was used as a basis for the overland flow grid. A nested grid is used to model overland flow: the size of grid cells is chosen at 25x25 meter in areas with few spatial variations in occupational land use, to limit calculation time. A higher level of detail is required in the urbanized area; here the grid size is chosen at 5x5 meter. The median of the surface levels found in the AHN2 is used to determine the surface level in the grid cells. The overland flow module is used to determine the location at which water problems occur and what the water level is at this location. These factors influence the costs occurring from inundation.

Rainfall scenario In recent years the Oranjepolder was inundated a number of times. In August 2004 325 mm rain fell with four large rainfall events (Figure 2) which caused inundation. Inundation was found in the urbanized part and inside the greenhouses. In the notification systems of both the water board and municipalities reports have been made. These reports containing a date, location and water level indication, have been used to assess the reliability of the rainfall fed inundation calculated by the hydrodynamic models. The entire month August 2004 is chosen as the simulation period.

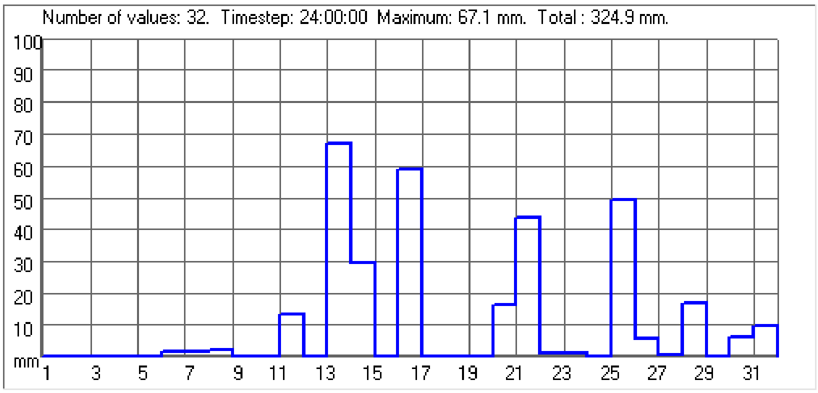

Figure 2: Daily rainfall measurements in August 2004 in Maasland

Three measurement stations are located in the close vicinity of the Oranjepolder. The water board of Delfland has two rainfall measurement stations (located in Maasdijk, in the Oranjepolder and in Schipluiden) and the Royal Netherlands Meteorological Institute (KNMI) has a daily rainfall station in Maasland. The distance between the measurement stations is approximately 10 kilometers.

Rainfall data with a time step of at most 15 minutes is required to model peak flows during heavy rainfall. Data of the rainfall measurement stations of the water board are available at an interval of 15 minutes. However, the station in Maasdijk did not register correctly until the end of September 2004. Rainfall data from the Schipluiden rain gauge were used as model input; the data were corrected according to daily values from the Maasland rain gauge, because the Schipluiden data are lower than those for Maasdijk from October onwards (Table 1).

Table 1: Rain gauge data Oranjepolder area 2004

Rain gauge	Maasdijk	Schipluiden	Maasland
Resolution	15 min	15 min	1 day
Monthly rainfall Aug [mm]	Not available	255	325
Monthly rainfall Oct [mm]	56.9	49.6	58
Max daily rainfall Oct [mm/day]	10.2	9.4	9.4

The correction was based on the daily measurements from Maasland and the measurements at Schipluiden with a 15 minute interval. Using Formula 1 the rainfall data at Maasdijk (with an interval of 15 minutes) was created.

$$P_{Maasdijk}^{15min} = P_{Maasland}^{daily} \frac{P_{Schipluiden}^{15min}}{P_{Schipluiden}^{daily}} \qquad (1)$$

P: measured rainfall in [mm] with temporal scale and location

Inundation reports

Both the municipality and water board have a report system that is used by citizens to report water problems. During the month August 2004, 45 reports were made of inundation in the Oranjepolder. The reports consist of a dates and qualitative descriptions of locations and water depths of the inundation. Details of the four largest rainfall events and the reports are shown in Table 2.

Table 2: Characteristics of rainfall events in August 2004, based on corrected data Schipluiden rainfall station

Event	Date [August 2004]	Total volume [mm]	Max intensity [mm/15min]	Duration [hours]	Nr of reports
1	13th	96.6	13.1	48	19
2	16th	59	22.8	24	16
3	20th	60.2	15.2	31	3
4	25th	49.1	13.3	24	3

3 RESULTS

Sewer system spills

The integrated modeling of the sewer system and surface water makes it possible to analyze interactions between the two systems. On the August 16 of 2004 the inundation in the village Maasdijk is analyzed in detail. The situation when the inundation was at its maximum is presented in Figure 3. The spill location of the sewer system is indicated by the circle. The overland flow simulation shows to what extent greenhouse, streets and houses are inundated.

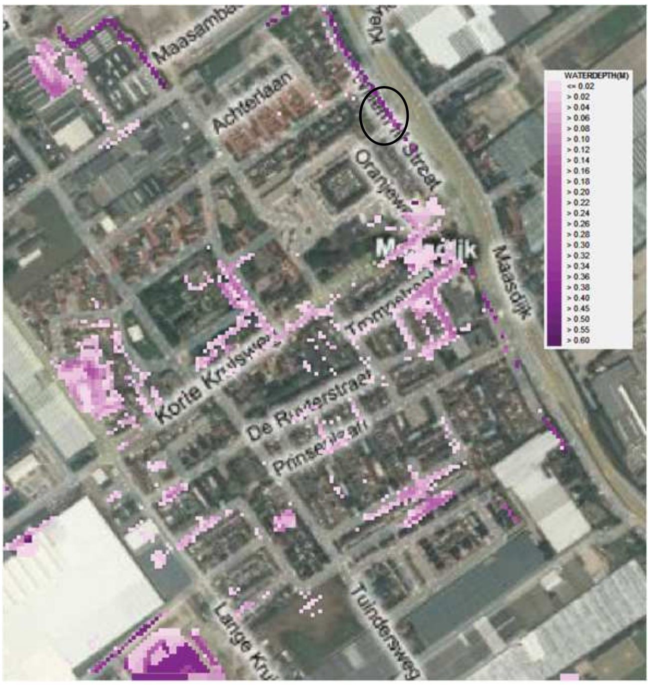

Figure 3: Inundation in the urbanised area

The interaction between the surface water system and sewer system is analyzed in detail. A side view for an inundated part of the village to the nearest spill way gives a water level trajectory shown in Figure 4. It can be seen that both the sewer water level and the open water level are above crest level. The weir is “drowned” resulting in a non-free flowing spill. The water level in the sewer system is above the open water level, so there is a flow towards the open water controlled by the height of the surface water level.

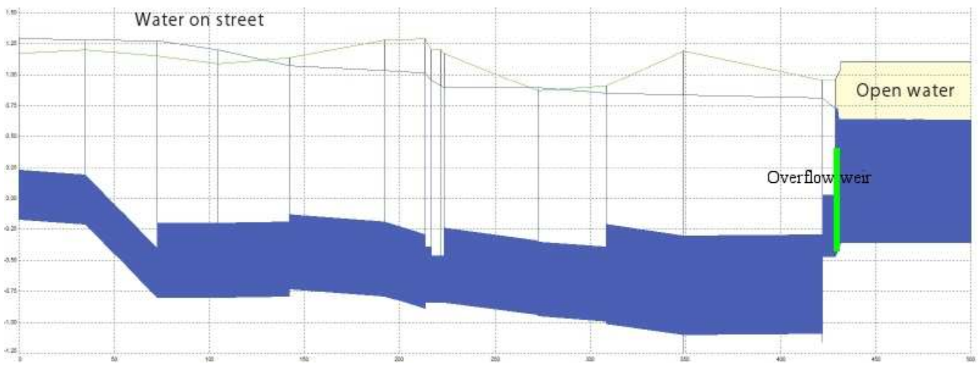

Figure 4: Longitudinal section of sewers and outflow to open water

The graph in Figure 5 shows the water level rise in the sewer system during a rainfall event. When the water level exceeds the crest level of the spill, water starts discharging to surface water. The surface water level rises both as a result of this spill and of direct runoff to the channel. At the moment that the water level of the open water approaches the water level of the sewer system, the discharge from the sewer decreases. When the water level in the open water rises above the sewer water level the discharge comes to a halt. Water is prevented to flow into the sewer system by an automatically closing valve. The water level in the sewer system decreases by drainage by a pumping station.

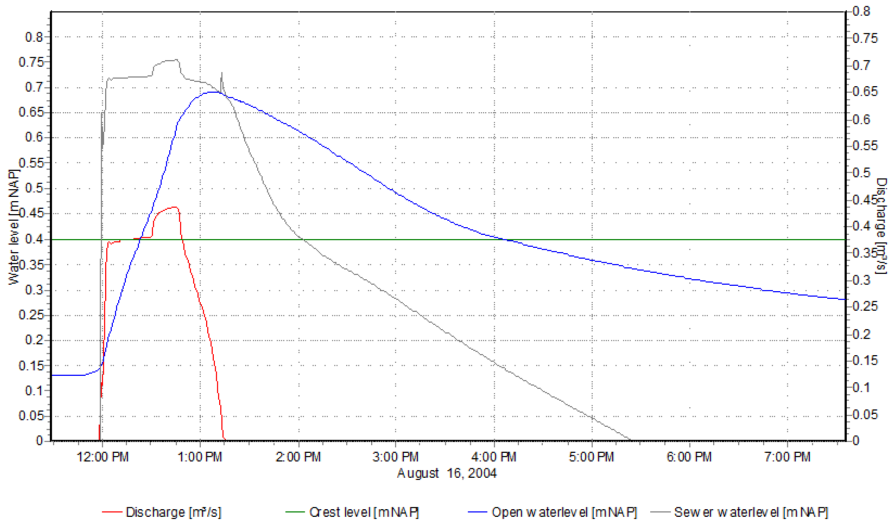

Figure 5: Discharge of sewer on open water

Greenhouse spills

Inundation occurred on August 16, 2004. The greenhouses which discharge on the open water close to the inundation are analyzed in detail. Greenhouse water storage levels and their runoff discharge to open water are shown in Figure 6. It is found that the greenhouse storage was almost completely empty at the beginning of August. Heavy rainfall before August 16 (over 100 mm) filled the storage completely. The water use for crop irrigation drains the storage only a little in the period between the 14th and 16th august. The storm event on the 16th of August creates a large spill to the open water.

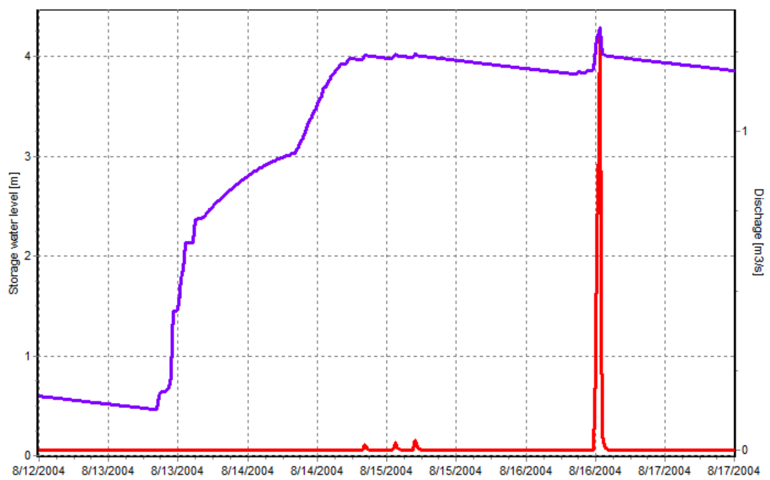

Figure 6: Example of the model result of a greenhouse storage with discharge to open water

Inundation locations

The integrated hydrodynamic model has been used to analyse the flooding situation in the Oranjepolder. Reported inundation locations were confirmed in most cases by model calculations: 8 out of 10 were confirmed, while 2 were not confirmed. Based on the model calculation and inundation reports, hydraulic problems were identified in the system and these insights were used to develop solutions for improved flood protection.

Solutions for improved flood protection Oranjepolder

This research has contributed to a better insight into inundation problems in the Oranjepolder. Three solutions which are now undergoing further investigation are:

1. Use of greenhouse storage basins for peak rainfall retention. In the Oranjepolder almost 400.000 m^3 of storage volume has been created by horticulturists near their greenhouses for irrigation of greenhouse crops. Storage volume at greenhouses needs to be made available where and when this storage is needed for peak rainfall retention. This requires cooperation between the water board and horticulturists as well as a reliable rainfall forecast. Research on the implementation is currently being conducted.
2. Rearranging the sewer system in the village Maasdijk. The municipality is investigating the possibility to change the combined sewer system into a separate system. Additional spill locations can be created for the stormwater system, shortening transport routes for stormwater, thus reducing flooding probability.
3. Adding a drainage point from the open water system in the polder towards the surrounding belt canal. The water level in the polder near Maasdijk can be controlled by creating a weir which is only active in case of extreme water levels.
4. One of the measures is to increase the drainage capacity through the polder. By creating two new larger channels connecting the northern to the southern part of the ring channel. Water levels in the higher northern part can be limited by an increased flow to the southern part to be discharged out of the polder.

4 Conclusions and future prospects

The hydrodynamic model of the Oranjepolder has a high level of detail, in which the important hydrologic processes are included:

1. The hydrology of greenhouses. In the new model individual greenhouses are included. This results in a runoff to open water which represents the actual situation.
2. The channel flow model contains all channels and water structures located in the polder. This makes it possible to analyse inundation for every channel.
3. The sewer system of the village Maasdijk is included in the model. Interactions between the sewer system and overland flow and between sewer system and surface water system are taken into account in the analysis.
4. Finally, the aspect of overland flow is included for both the sewer system model and the surface water system model.

By taking all these hydrologic processes into account, predictions with a high temporal and spatial resolution can be made. The high modeling resolution leads to a better insight into the factors that influence inundation.

A limitation of this modeling approach is the large amount of required data and long calculation times. To achieve the high level of detail in model output, a large amount of data was required. Modeling all greenhouses with a correct water balance and discharge location is time consuming. A model simulation takes 1/20th of the simulation period, i.e. 1.5 days for the simulating the month of August (although this is dependent on the calculation time step).

The integrated approach used in the Oranjepolder has led to the identification of solutions that could not be identified by the traditional modelling approach. The high resolution model including a more realistic representation of greenhouses storage basins, interactions between sewer and surface water systems and overland flow processes was able to localise the causes of inundation problems at a detailed level. Thus, localised solutions could be identified and tested for their efficiency, such as local water storage at the greenhouse level and the addition of spill locations for the sewer system and surface water system.

New developments in the simulation approach for inundation modelling will help to overcome the problems of long calculation times associated with detailed DEM data. A new modelling approach is for instance introduced in the 3Di innovation project (3Di Waterbeheer, 2010). The novelty of this method is the use of a flexible calculation grid that is automatically adjusted by the model depending on elevation variability. This makes the calculations over a 100 times faster, while making it possible to work with a resolution 10 times higher than current simulation models. At this moment the 3Di modeling software is still under development, inclusion of 1D components such as a sewer system and controllable weirs is foreseen in the near future.

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