Network of stormwater pumping stations designed to enhance and stabilize the urban drainage system

Conception d'un réseau de stations de pompage des eaux pluviales pour améliorer et stabiliser les systèmes d'assainissement urbains

Makoto Tanokura*, Minoru Nakada**, Kazumasa Kudo*, and Osamu Matsushima*

* Japan Institute of Wastewater Engineering Technology (JIWET), 3-1 Suido-cho, Shinjuku-ku, Tokyo 162-0811, Japan (m-tanokura@jiwet.or.jp)

** Takenaka Civil Engineering and Construction Co., Ltd., 1-1-1 Shinsuna Koto-ku, Tokyo 136-0075, Japan

RÉSUMÉ

Au cours des dernières années, l'augmentation du nombre d'évènements pluvieux intenses a donné lieu à des volumes d'écoulement d'eau de pluie qui dépassent fréquemment la capacité des systèmes d'assainissement existants. Dans le même temps, les stations de pompage des eaux pluviales connaissent une usure progressive et bon nombre d'entre elles doivent être renforcées pour répondre aux exigences parasismiques. De nombreuses stations de pompage vont devoir être reconstruites pour améliorer leur capacité de pompage des eaux de pluie et assurer une meilleure protection parasismique. Cette étude propose une nouvelle approche des problèmes d'inondation par l'élaboration d'un réseau de stations de pompage connectées entre elles, ce qui faciliterait également leur reconstruction. Dans cette communication, les auteurs proposent des techniques de planification pour le développement de réseaux de stations de pompage des eaux de pluie, ainsi que des méthodologies pour déterminer la taille des installations et évaluer les résultats opérationnels.

MOTS CLÉS

Station de pompage des eaux de pluie, réseau, systèmes d'assainissement urbains

ABSTRACT

An increasing incidence of concentrated rainfall events in recent years has led to stormwater outflows that frequently exceed the processing capacity of existing stormwater drainage facilities. Meanwhile, stormwater pumping stations are steadily deteriorating through age, with many requiring seismic reinforcement. A large number of pumping stations will need to be rebuilt in order to boost the stormwater discharge capacity and provide better seismic protection. This study considers the concept of networks of interconnected pumping stations as a new approach to the problem of inundation which also facilitates the rebuilding of pumping stations. In this paper, the authors propose planning techniques for developing networks of stormwater pumping stations, as well as methodologies for determining the facility size and for evaluating outcomes.

KEYWORDS

Stormwater pumping station; network; urban drainage systems

1 INTRODUCTION

In recent years, an increase in concentrated rainfall events in Japanese cities, combined with the ongoing process of urbanization, has led to frequent incidents of inundation when stormwater outflows exceed the stormwater drainage capacity of the sewerage system. Meanwhile, cities are becoming extremely advanced, as exemplified by higher concentrations of assets and the ongoing trend towards underground development, and this increases the potential for inundation to cause major damage. It is therefore important to raise the standard of the stormwater system while incorporating appropriate protection from inundation into town planning and urban design. However, boosting the capacity of existing facilities is a long-term proposition that cannot be expected to yield immediate benefits.

Meanwhile, many stormwater pumping stations in urban areas are in an advanced state of deterioration but there is limited land area available for rebuilding. The key issue therefore is how to rebuild or upgrade pumping stations effectively without compromising current discharge capacity.

This study proposes the development of a stormwater pumping station network as an efficient and effective solution to the rebuilding of stormwater pumping stations which will raise the standard of the stormwater system. The study also examines the benefits of the network approach based on case studies.

2 STORMWATER PUMPING STATION NETWORK PLAN

2.1 Basic concept

Figure 1 shows the basic concept of the stormwater pumping station network. The network consists of existing pumping stations linked by pipes, complemented by additional pumping stations built as needed to service the pipe network. (Drainage pumping facilities may not be required at some of the smaller pumping stations.) When the network is complete, pumping stations will be able to direct stormwater into the network pipes in addition to the traditional discharge points. Stormwater can then be sent from the network pipes to public waters in a systematic manner as determined during the planning phase.

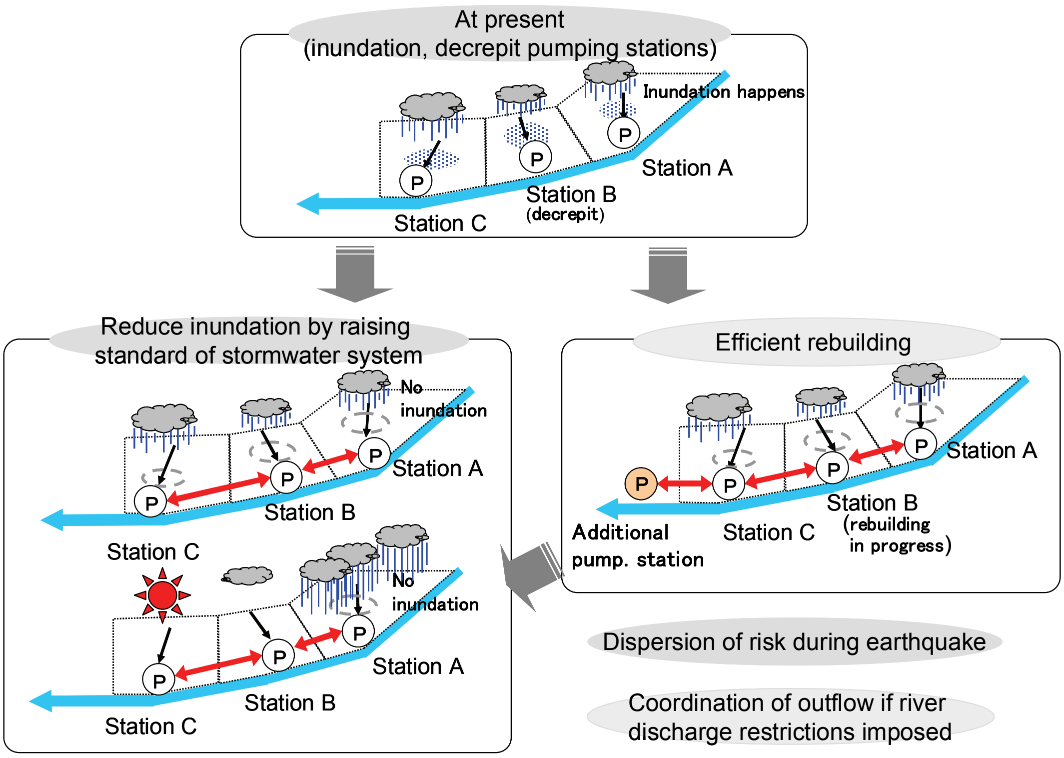

Figure 1 Concept diagram for stormwater pumping station network

Table 1 presents the anticipated benefits of the network concept and other key considerations. When the volume of stormwater to be discharged exceeds the discharge capacity of the facility, excess stormwater can be diverted to the network pipes, where it may be stored temporarily or discharged via dedicated drainage pumping stations, thus boosting the standard of the stormwater system using the existing pipes and reducing inundation. Similarly, the network can be used during the rebuilding of existing pumping stations to maintain the current drainage capacity.

The stormwater pumping station network also enables a coordinated and complementary response from pumping stations, thereby dispersing the damage risk in the event of earthquake, boosting the capacity of the stormwater system during intense rainfall events (localized and/or concentrated) and allowing more flexible regulation of outflows during periods of river discharge restrictions.

Objectives	Benefits	Key considerations
Boosting the standard of the stormwater system	• Reduces the frequency and scale of inundation incidents • Other pumping stations can provide capacity in the event of equipment failure at a pumping station	• Stormwater from one drainage district may be discharged by a pumping station in another district (necessitating river management conferences) • The standard of the stormwater system is constrained by the capacity of the existing pipes
Efficient rebuilding	• Other pumping stations can provide capacity during the rebuilding phase • Developing a network is less costly than providing a temporary replacement during the rebuilding phase	• Need to maintain current standards
Diversification of operations	• Helps to mitigate water damage during intense rainfall events (often localized and/or concentrated) • In the event of earthquake, other pumping stations can contribute capacity to an emergency response • Improved regulation of discharge flows during river discharge restriction periods by using network facilities for water storage	• Potential for higher risk of inundation at downstream end

Table 1 Main objectives and benefits of the network

2.2 Planning process

The proposed network is an integrated plan with two key objectives: to improve the overall standard of the stormwater drainage system (including multiple pumping stations), and to enable the rebuilding and upgrading of aging stormwater pumping stations in an efficient and effective manner.

Figure 2 outlines the planning process. The river basin to be covered by the stormwater pumping station network is selected on the basis of urgency, as determined by a range of factors including infundation levels, the age of the stormwater pumping stations, the level of earthquake protection, site conditions, and the level of development of the rivers used for discharge. The first step in formulation of the plan is to draw up a set of general planning principles regarding the necessity for rebuilding and the redevelopment objectives, based on an assessment of the level of inundation damage and the conditions of the facilities. The next step involves preparing several different network planning proposals and determining the scale of facilities required in order to improve the standard of the system, including the extent of rebuilding at existing pumping stations and the size of the networking facilities. The size of the networking facilities is then confirmed via an analysis of incremental implementation.

An analysis of network operation is used to evaluate the various network planning proposals in terms of response to situations such as river discharge restrictions and possible interruptions to draining capacity during localized and/or concentrated intense rainfall events and other natural disasters. On the basis of this analysis, an overall evaluation is conducted to select the optimum proposal.

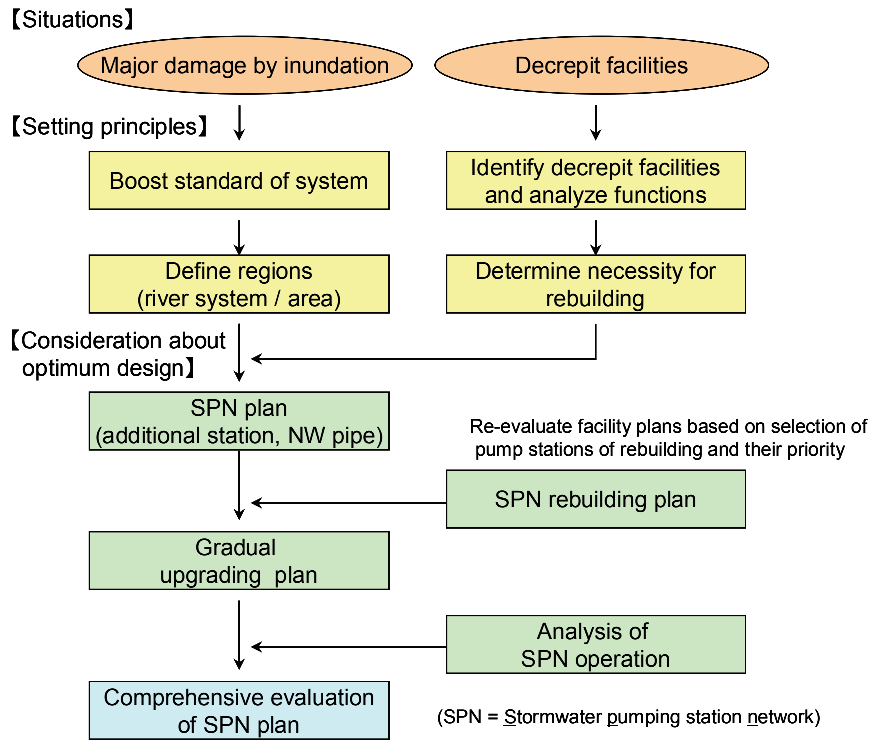

Figure 2 SPN planning process

2.3 Possible storage configurations of network pipes

2.3.1 Full storage network pipes

Network pipes are used to store stormwater. As such, the cross-sectional area (i.e., the size) of the pipes is large enough to accommodate stormwater storage equivalent to normal flows through to pumping stations during planned rainfall minus the maximum drainage flow (called the “allocated network volume”). This requires the largest pipe size of the three configurations.

2.3.2 Outflow network pipes with additional drainage pumping stations

Network pipes are used solely for carrying stormwater flows. The pipes are designed to accommodate planned network outflows. Drainage pumping stations for storage pipes have adequate discharge capacity for the allocated network volume. This configuration has the smallest pipe size; however because stormwater is not stored within pipes, this configuration does not allow regulation of discharge flows into rivers.

2.3.3 Outflow/storage network pipes with additional drainage pumping stations

Network pipes are used to carry stormwater flows and also for limited storage. Flows to additional pumping stations are restricted, with any excess stormwater directed to the network pipes for storage.

In this configuration, the network pipes are larger than in configuration ***2.3.2*** above while the drainage capacity of the pumping stations is smaller. The actual cross-sectional area is dictated by the flow restrictions. Storage of stormwater in network pipes enables regulation of discharge flows into rivers.

2.4 Facility design

2.4.1 Boosting the standard of stormwater drainage facilities

Pumping stations are assigned a planned drainage volume designed to achieve the development objectives at the station location. Based on past rebuilding projects, pumping stations rebuilt within the existing site area would be no more than 50% larger than their original size, even once the network is operational. The allocated network volume is determined from the rebuilt pumping stations. The scale of the network facilities is designed to accommodate the allocated network volume.

2.4.2 Efficient rebuilding/upgrading

It is unfeasible for pumping stations to suspend drainage operations altogether during rebuilding or upgrading works. Accordingly, network facilities must be designed to ensure that current capacity can be maintained during the rebuilding/upgrading phase.

2.4.3 Incremental implementation of network facilities

Rebuilding of stormwater pumping stations is a long-term exercise. Incremental implementation provides a means of achieving immediate outcomes in some areas while addressing the deterioration of facilities, taking into account regional characteristics and the potential for utilizing temporary measures. The required facility size is determined at each stage within the context of the final development plan, with reference to limiting factors such as the timing of land acquisition and the limit of the annual budget as well as other factors such as river capacity and level of development. At the intermediate development stage, a simulation is performed at current planned rainfall levels to ascertain that rebuilding of the pumping station will not compromise the existing standards, and the facility size is determined as required.

2.4.4 Operation of network facilities

The stormwater pumping station network links together multiple drainage districts over a large area, allowing pumping stations and other facilities to augment one another. An analysis is performed to evaluate the efficiency improvements provided by the network, focusing in particular on: (1) intense concentrated rainfall events; (2) risks associated with natural disasters; and (3) discharge restrictions in rivers.

3 CASE STUDY TO CONFIRM EFFECTS OF THE NETWORK

The benefit analysis of network facilities considers the reduction in water damage achieved by the network, as well as the potential risk of a shift in inundation areas. Figure 3 shows a sample analysis conducted during the pumping house rebuilding phase in the model region. The existing plan for boosting standards assumes that storage pipes are allocated to each pumping station river basin to augment the pumping house capacity. During the rebuilding of pumping station A, it is not possible to set up a temporary pumping station nearby, so drainage capacity would be inadequate for normal rainfall levels and inundation would occur. With a network, however, storage pipes from the various pumping station river basin areas would be linked together. An additional pumping station would be built in the lowest reaches, and stormwater from the pumping station A river basin would flow through the network pipes while the seed pumping station would provide alternative drainage capacity. In this way, overall drainage capacity would be maintained during the rebuilding phase.

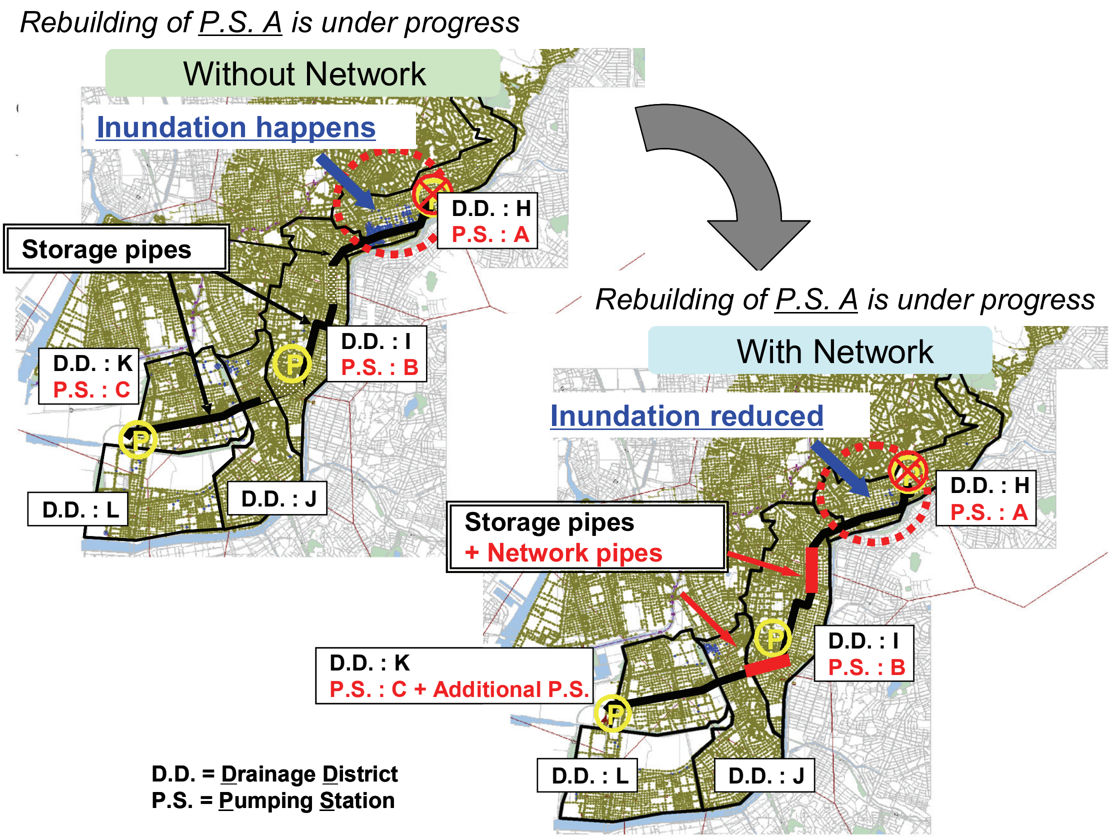

Figure 3 Effects of network when rebuilding is in process

As a additional case, we assumped exceeding rainfall shown in Figure 4. The analysis assumes rainfall of 93 mm/hr (well in excess of the normal planned rainfall figures) concentrated in district L, which would exceed the capacity of a single pumping station. Figure 5 shows a result of analysis when the network is operational. It can be seen that, through utilization of capacity from other pumping stations, the network effectively reduces the area affected by inundation in the event of intense and concentrated rainfall. And now, we used “Infoworks CS” as a calculation model for this case study.

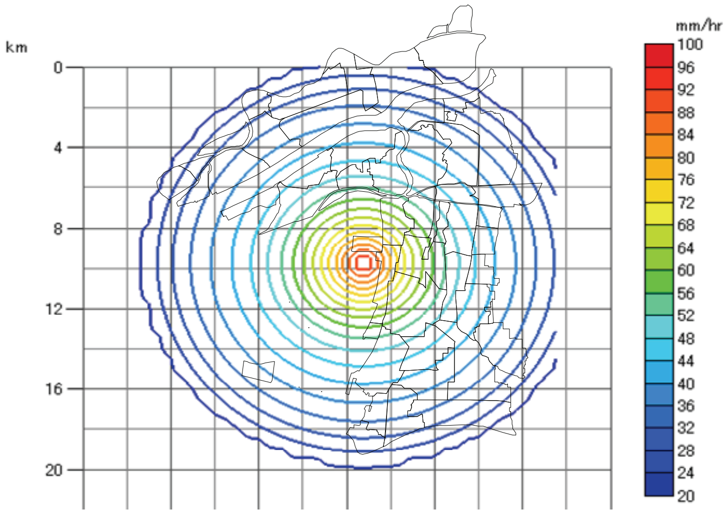

Figure 4 Assumption of exceed rainfall for case study

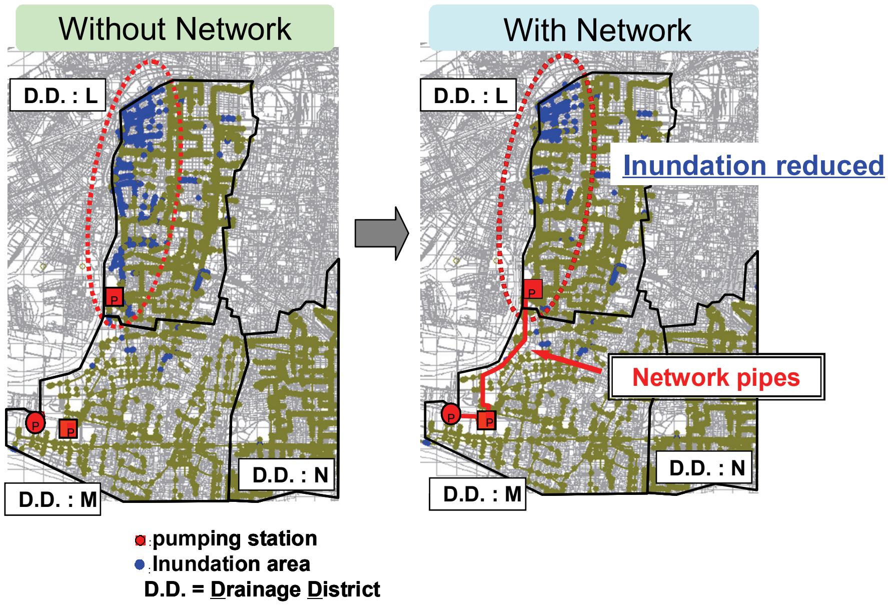

Figure 5 Effects of network when intense rainfal occurs

4 DISCUSSION

It is expected that there will be more opportunities for studies and projects involving consolidation of stormwater pumping station river basins with a view to boosting the standard of existing drainage systems and rebuilding existing pumping stations. At the same time, the anticipated benefits of the stormwater pumping station network will differ depending on the stage of development. For this reason, it is important in the planning phase to use inundation simulations to examine the potential risk of a shift in inundation areas and network pipe flow analysis to ascertain the ultimate benefits of the network, in addition to considering possible configurations for linking together existing pumping stations.

Meanwhile, JIWET(2008) and JSWA(2006) has shown the way how to evaluate damage cost. In case considering about multiple plans, it is better to evaluate damage cost by inundations.

5 CONCLUSIONS

In this study, we confirmed the two key benefits of the stormwater pumping station network: enabling efficient and effective rebuilding of pumping stations, and boosting the standard of the existing system.

At the same time, necessary considerations to determine the planned facility size were organized: which are, storage configurations of network pipes, additional pumping stations are to be built or not, and plan of gradual updating.

As a result of case studies, it was confirmed that the stormwater pumping station network will reduce water damage associated with concentrated intense rainfall events.

LIST OF REFERENCES

Japan Institute of Wastewater Engineering Technology (JIWET) (2008). *Stormwater pumping station network planning manual*. (Japanese only)

Japan Sewage Works Association (JSWA) (2006). *Cost-benefits analysis manual for sewerage works (draft).* (Japanese only)

Japan Sewage Works Association (JSWA) (2008). *Cost-benefits analysis manual for sewerage works (draft)—supplement.* (Japanese only)