Strengthen resilience to rivers flooding by the drag reduction technique

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Abstract. Urban agglomerations face the risk of overflowing rivers due to intense urbanization in flood-prone areas and the climate change effects. Despite the important protective measures deployed to reduce the fluvial flooding risk, additional efforts are still needed. This work aims to propose a new complementary non-structural protection measure, used to reduce the river flooding risk. The study is part of the NABRAPOL (NEBRASKA POLYMER) project, which aims to improve knowledge of the drag reduction effect by adding polymers in open-channel flows. The addition of polymers, even in limited concentrations, allows high friction to decrease with the typical Manning coefficient reduced up to 45%. An application case on a real watercourse is presented in this article. Two measurement campaigns are carried out on a river along 30 km. Experimental devices are deployed, and non-intrusive hydraulic measuring instruments are installed at the study field. Surface velocities are evaluated by the Large-Scale Particle Image Velocimetry (LSPIV) technique, and water depth is measured using ultrasonic radar sensors over the river. Measurement results show that the addition of 20 ppm of polymers in the flows results in a marked drag reduction by decreasing the water depth to 18% of its initial depth. The drag reduction technique by addition of small concentrations of polymers can be considered as a new and effective method to reinforce the measures already deployed in the flood risk management strategy since it allows the water depth to be decreased thus avoid overflowing rivers in the extreme flooding event.

Keywords: friction, polymers, flood, boundary layer, LSPIV, flood risk.

1. Introduction
Floods are the most common natural disasters often resulting in considerable economic losses and human and social tragedies [1]. The extreme events in the Caribbean, Bangladesh, and Japan in 2017, India and the Philippines in 2018, show just how devastating the effects of flooding can be. In addition, some mega-cities such as Bangkok, Mumbai, Jakarta, Shanghai, Saigon, Dhaka, London, Paris, and Rotterdam are extremely vulnerable to river flooding due to increased risks associated with urbanization and the effects of climate change [2].

An effective system of protection against the risk of river flooding can significantly improve public safety, reduce social damage and economic losses associated with flooding. Consequently, flood risk management is still a huge challenge for the government and local authorities [3], especially when the adaptation of the riparian population facing the risk of flooding is constantly evolving.

The preferred technique to fight against floods is currently the protection strategy [4]. The drag reduction method by adding polymers can be considered as an effective new technique to reinforce the
measures already deployed in the strategy of flood risk management since it makes it possible to reduce the water depth up to 18% of its initial water depth [5] and therefore avoid the overflow of rivers in the flood event.

Discovered by Toms in 1948 [1], the drag reduction by adding polymers is a strategy used to minimize friction in long-distance closed-conduit flow. Industrial applications of polymers began in the 1970s and are growing steadily in different sectors. They are commonly used in pipelines, oil wells, firefighting, irrigation, sewerage systems, water heating and cooling systems, marine systems, and aeronautics [2].

The drag reduction effect allows for dramatic reductions in wall friction and thus linear head losses of up to 80% [6-7]. The origin of this phenomenon lies in the turbulent structures of the flow and the polymer macromolecules added to the fluid [8]. In a fully developed flow over a smooth bed, the polymers modify the velocity profile in the boundary layer. With clear water, the velocity profile in the near-wall regions is composed of a laminar viscous sublayer very close to the wall: \( \frac{y u}{\nu} < 10 \), where \( y \) is the distance to the wall, \( u^* \) is the friction velocity \( u^* = \sqrt{\tau_w/\rho} \), \( \tau_w \) is the shear stress at the wall, \( \rho \) is the fluid density and \( \nu \) is the kinematic viscosity of the liquid and the log law slightly further away: \( \frac{y u^*}{\nu} > 50 \). When adding polymers, a so-called elastic zone can be observed in between these two zones for \( y^* > 15 \) [9-10], within which the velocity profile follows a logarithmic law with a slope that depends on the polymer concentration. It has been reported that as the extension of this zone increases, the drag reduction efficiency also increases.

Virk [9] also investigated the possibility of using polymers to reduce the drag over rough surfaces. He observed that for walls with a large enough roughness element, the wall roughness tends to decrease the drag reduction process. Using the nondimensional roughness height \( K_r^+ = K_r u^*/\nu \), where \( K_r \) is the equivalent sand roughness height, Virk [9] showed that for \( K_r^+ > 50 \), drag reduction efficiency decreases compared to a flow over a smooth surface. This holds up to the experimental limit of \( K_r^+ \) of approximately 150. Mignot et al. recently confirmed this reduced efficiency of polymers over a rough surface with \( K_r^+ \) in the range of 100–135 [11].

Most of the studies reported the use of drag reduction polymers in pressurized pipe or channel flows. However, a few tests have also been performed in open-channel flows, especially within sewer systems [12]. Hart et al. [13] reported the use of such polymers in the sewer network of the city of Whistler, Canada during the 2010 Winter Olympic Games, where the wastewater discharge was strongly increased due to a particularly high population in the area. Including polymer additives in the wastewater decreased the water depth and increased flow velocity, leading to an increased discharge capacity of the sewers. The authorization for releasing polymers in sewer flows was based on a materials safety data sheet (MSDS) that indicated that the chemicals were nontoxic at limited dose concentrations [13].

Mignot [11] works on an open canal flow at the laboratory scale showed that by adding a limited concentration of polymer (approximately 20 ppm) to a steady flow, the Darcy-Weisbach friction coefficient decreased by a factor of 2 in a flow over a smooth surface and by a factor of 1.5 in a flow over a rough surface. The same observation was noted by Janosi et al. [14] in their work on investigating the effect of adding polymers to a dam-break flow experiment on both initially dry and wet beds.

This literature review suggests that this method may have some potential for increasing the bank-full discharge in watercourses. Following this interpretation, the authors hypothesized that similar phenomena also occur at the scale of a river of several kilometers. The aim of the present study was to assess the possibility of decreasing the water depth of a large-scale watercourse by adding polymers.

2. Materials and Methods

2.1. Study Field and Measurement Points
The open channel selected for this study is the Tri-State Canal, maintained by the FIDO (Farmers Irrigation District Office) in Scottsbluff, Nebraska (USA). The length selected for the trial is 40 km. The water depth varies along the canal from 0.85 to 1.50 meters in flow conditions suitable for testing. The
canal width varies between 18-21 meters, the small slope is of the order of $S_0 \approx 10^{-4}$. The canal bed contains pebbles, gravel, and alluvium. Strickler’s roughness coefficient is 50.

![Image](image.png)

**Figure 1.** The Tri-State Canal at Scottsbluff and the sediments of its bed.

34 km upstream of the injection site, there is a mobile dam managed by FIDO, allowing to adjust the flow rate and control water depth. The flow of the Tri-State Canal is steady and uniform, the regime is fluvial with an average velocity of 50 cm/s, the flow rate during this measurement campaign is $10 \text{ m}^3/\text{s}$. The Manning friction coefficient is about $n = 0.017$. The outside temperature was about $17\degree \text{C}$. The flow in the canal is turbulent, the hydraulic characteristics are summarized in Table 1.

| $V$ (m/s) | $H$ (m) | $Q$ (m$^3$/s) | Fr | Re   |
|----------|--------|--------------|----|------|
| 0.5      | 1.3    | 9.65         | 0.4| $5 \times 10^3$ |

**Table 1.** Flow hydraulic characteristic of the Tri-State channel.

![Image](image.png)

**Figure 2.** Study site and identification of monitoring points.

2.2. *Polymer Injection and Experimental Devices*

The polymers used were anionic polyacrylamides (FLOJET CRP 26), synthesized by copolymerization of AMD and acrylic acid, produced by SNF, in powder form, of very high molecular weight ($20 \times 10^6$
Da), soluble in water. The polymer concentration of the solution introduced into the canal was set to $C = 20$ ppm by adjusting the mass rate of polymer powder to the flow rate of the canal: $Q_{\text{m-polymer}} = C \times \rho_{\text{water}} \times Q_{\text{water}} = 696 \text{ kg/h}$, with $\rho_{\text{water}} = 1,000 \text{ kg/m}^3$. For an injection lasting 14 consecutive hours. The supplied quantity of water-soluble polymer reached 12 tones. The polymer solution was continuously injected into the Tri-State Canal at the upstream section from 6:00 a.m. until 9:00 p.m.

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The installation consists in hydrating the powder polymer before injecting it into the watercourse. The hydration is made using a polymer dispersing device which includes: 1) a hopper for continuous feeding of the polymer powder, 2) a metering device for polymer dispersion, 3) a polymer wetting cone connected to a water inlet circuit taken from the canal using a pump 4). The wetting cone is also connected to 5) a second adjustable flow rate volumetric pump ensuring the transfer of dissolvable polymer under pressure.

The polymer in suspension is injected into the Tri-State Canal continuously using a hose with an injection system containing 10 spray nozzles installed 1 meter above the width of the river to ensure a homogeneous distribution of the injected solution. This set-up provides a good mixture of the polymer with the canal water, and the suspension is quickly prepared before being injected into the canal. The experimental devices are illustrated in Figure 3.

![Figure 3](image_url)

**Figure 3.** (a) Polymer dispersion device located in a container installed next to the canal; (b) close-up view of the dispersion device, including hopper, metering device, wetting cone, pumping loop, flow rate volumetric pump, (c) injection system containing 10 spray nozzles.

2.3. **Measuring Devices**

*Water Depth Measurement.* A set of ten ultrasonic sensors are deployed during the campaign to measure the change in water depth after the polymer injection. Each sensor is fixed to each bridge
crossing the canal to measure the variation in distance between the position of the sensor and the flow surface level. Wooden planks fixed to the bridges were used for the vertical referencing of the measured levels. The sensor records the measurements automatically every 10 min. Thereafter, the water depth variation is deduced.

![Image](image1.jpg)

**Figure 4.** Water depth measurement technique.

A time-lapse camera was installed in front of a ruler to film the water depth variation at 15 km from the injection.

![Image](image2.jpg)

**Figure 5.** Installation of a time-lapse camera Link to the video: [https://vimeo.com/382568921](https://vimeo.com/382568921)

**Velocity Measurement.** Surface velocity measurements are carried out at each measurement point using Large Scale Particle Image Velocimetry (LSPIV). A widely applied technique for the estimation of hydrometric characteristics in fluvial flow [3]. Each measurement point is equipped with a smartphone containing a video camera filming one-minute videos every 30 minutes.

The various measurement instruments worked satisfactorily throughout the measurement campaign. The measurements carried out thus made it possible to define the change in flow hydraulic characteristics and create a reference datum for characterizing the drag reduction phenomenon.

**3. Results and Interpretations**

The time evolution of the water depth variation at the ten bridges is depicted in Figure 5. This figure confirms previous experiments in laboratory conditions, that adding polymers to a large-scale watercourse reduces water depth. As the polymer arrived at a cross-section, water depth decreased quite linearly with time and eventually reached a lower plateau of maximum drag reduction with a constant reduced water depth. Measurements showed that the drag reduction phenomenon is reached after 46 min of polymer displacement time. A constant water depth corresponding to constant flow conditions is noted at first. Then, a change in flow regime is observed after 46 min of polymer displacement time. This delay corresponds to the time needed for a complete dissolution of PAM in cold canal water.

Water depth was reduced by up to 33 cm at Bridge #1; this represents 20% of the drag reduction. However, the percentage of drag reduction decreases as a function of the distance from the injection site (Figure 6).
Figure 6. Percentage of drag reduction of water depth variation for monitoring Bridges #1 to #10.

The measurement results also show that the water depth gradually decreases and then stabilizes 2 hours after the arrival of the polymer at each measurement point. This time corresponds to the maximum of DR. These experimental results demonstrate that the decrease in water depth depends on dissolution time and interaction time of polymer with the canal flow, which takes about two hours to obtain the maximum drag reduction effect. However, no variation in water depth was detected at 33 km.

At 37 km, i.e., 21h min of flow from the injection site, an increase in water depth (backwater) to 5% of its initial depth was observed. Indeed, the water height reduction provided by the DRP technique is due to a water flow acceleration. This water then accumulates downstream where the DRP effect is no longer effective. These tests made it possible to define the location of the second injection point to protect all areas, upstream and downstream, against flooding risks.

Velocity Measurement

The flow velocity is influenced by the polymer action on flow dynamics. For the different measurement points, it can be noted that velocity increased by up to 30% which corresponds to a reduction in water depth of 17% as shown in Figure 7. The article by Mignot et al [11], which is also based on the results of tests on an open channel in a laboratory, analyzes the phenomena at the origin of the velocity increase. The percentage increase in flow velocity in the canal also decreases as a function of the distance from the injection point.

Figure 7. Increase of velocity at bridge #3 at 7.3 km.
4. Conclusion
The present paper aimed at assessing the possible drag reduction by injection of a polymer in a large-scale open-channel watercourse and at measuring the water depth decrease and gain in discharge capacity. The measurement campaign made it possible to define the zones of change of the hydraulic characteristics the experiment presented here was a proof-of-concept of drag reduction by polymer injection at a large scale. It has been demonstrated by these tests that the polymer can increase the flow capacity by 30% and decreases the water depth up to 18% for a polymer concentration of 20 ppm. The analysis carried out in this work showed the non-variation of the physicochemical parameters of the canal water after the polymer injection. However, there are still other parameters to measure. From a technical perspective, the DR mechanics by the polymers remains to be studied in more detail. The processes of the flow change remain to be specified. Another test on the canal will help answer these questions.

5. Data Availability Statement
All data that support the findings of this study are available from the corresponding author upon request.

6. Acknowledgment
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