

Chemical and physical controls on arsenic removal from flowing irrigation water in Bangladesh

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INTRODUCTION

Across Bangladesh, millions of shallow tube wells are used to provide a source of irrigation water and increase dry season rice production. However, many of these wells pull groundwater from aquifers contaminated with high levels of arsenic (1). Accordingly, after years of irrigation, arsenic concentrations have increased in rice field soils (2,3), leading to reduced rice yields (3,4,6,7) and increased arsenic concentrations in rice grains. Consumption of contaminated rice can account for up to 50% of annual arsenic intake in Bangladesh (5), representing a significant contribution in a region dealing with arsenic-contaminated drinking water and rampant with cases of arsenicosis (low-dose arsenic poisoning). Due to the volume of water involved in irrigation, there are no current technologies or methods available to prevent arsenic loading to rice fields. Distribution systems made of native soils can remove arsenic from flowing irrigation water by promoting sorption to soils or co-precipitation of arsenic-bearing solids, as indicated by observed decreases in arsenic concentrations along flow channels and across rice fields (6, 7). However, the chemical and physical controls driving these reactions have yet to be resolved, limiting our ability to manage irrigation in a way that maximizes arsenic removal prior to field application.



PROJECT GOAL

Evaluate processes controlling arsenic transport in flowing irrigation water to determine the potential for low-cost management strategies that reduce arsenic deposition onto rice field soils.

RESEARCH OBJECTIVES

- Determine the factors controlling the spatiotemporal variability of arsenic concentrations in flowing irrigation water.
- Evaluate the impact of different chemical processes on arsenic concentrations.
- Examine management options to reduce arsenic loading to rice field soils.

MATERIALS & METHODS

Field experiments were conducted in Bangladesh to examine arsenic concentrations over space and time in modified irrigation channels.

Site Description

Experiments were conducted at a well-characterized site in Mushiganj, ~30 km south of Dhaka. Rice fields at the site are irrigated from a central well containing **400 µg/L As** and high dissolved Fe. A network of channels distributes water from the well to fields.

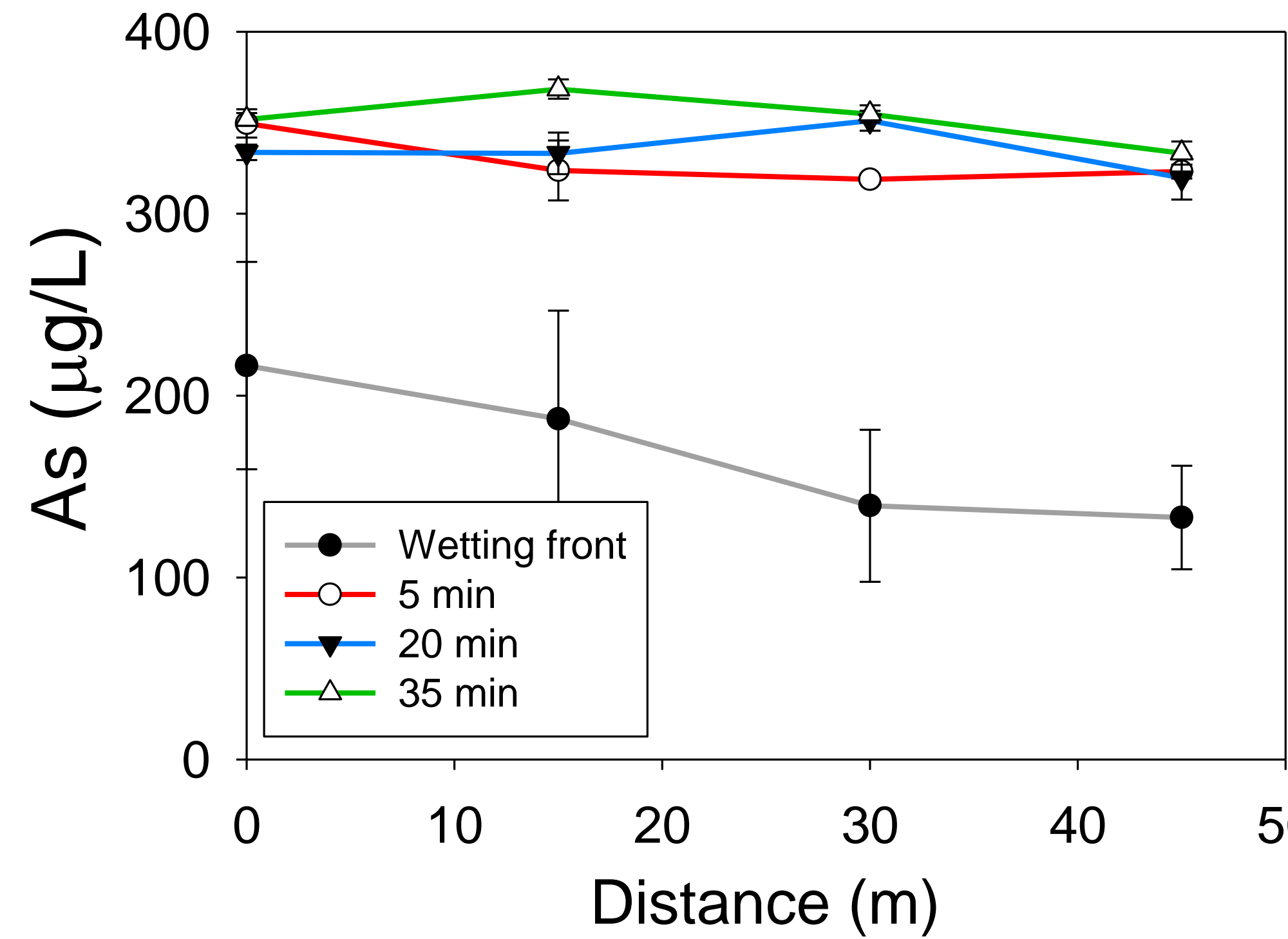
Variables Tested (all experiments in triplicate):

- **Channel Width:** Channel widths of 43 cm (the typical channel width), 89 cm (2X), and 137 cm (3X) were examined.
- **Channel Length:** Typical experimental channels were 45 m long and were sampled every 15 m. A long channel composed of 4 of the channels connected together achieved a length of 200 m.
- **Time:** Samples were taken at varying time points, from the wetting front (0 minutes) up to 45 minutes.
- **Lining:** Lined channels to prevent soil-water contact were tested.



RESULTS

Arsenic Variability in a Typical Channel



Wetting front
Turbid slurry present along the wetting front results from water rushing into the channel .

Figure 1. The greatest decrease in arsenic concentrations is observed along the wetting front. Sampling time impacts arsenic concentrations more than distance. The wetting front has increased ratios of atmospheric and soil contact to water volume compared with later time points. This enhances oxygenation of water, oxidizing iron and, to a lesser extent, arsenic. The formation of iron oxide precipitates removes arsenic from solution through co-precipitation, and arsenic may also sorb to channel walls. At later time points, many potential sorption sites have already been filled and higher irrigation water volumes lead to less overall oxygenation. Data points represent the average of three experimental trials, and error bars represent standard error.

Soil-Water Contact

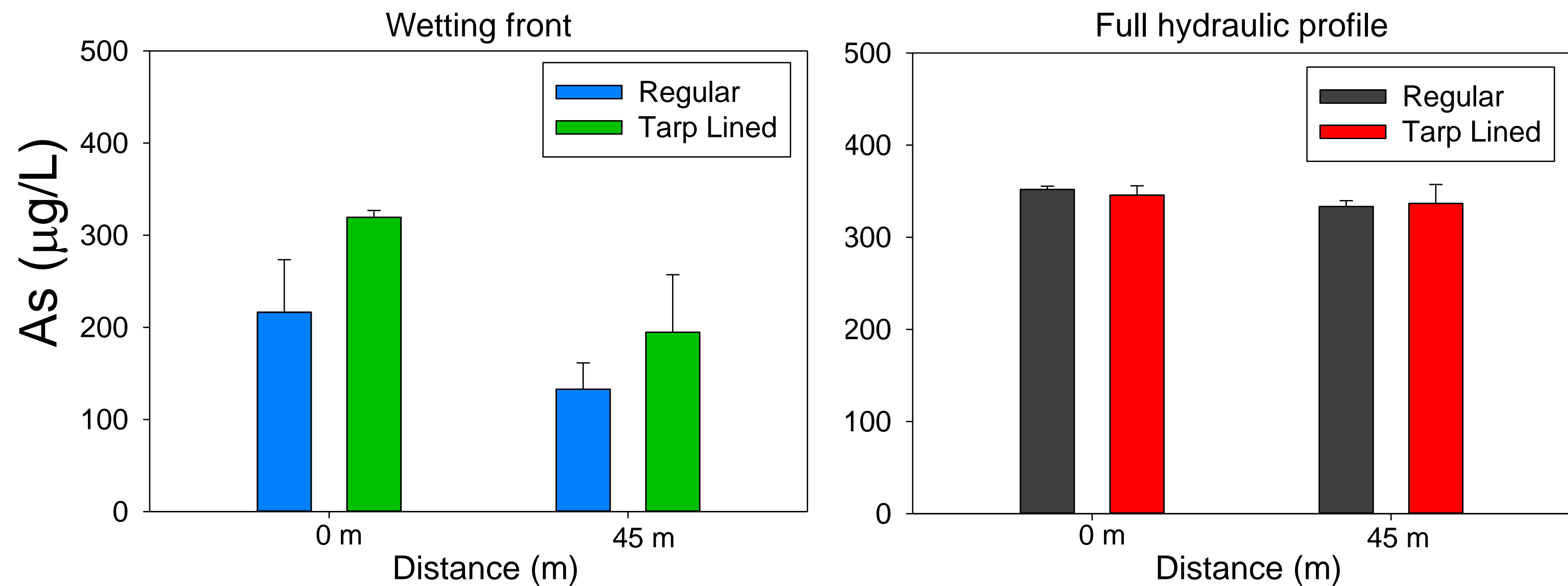


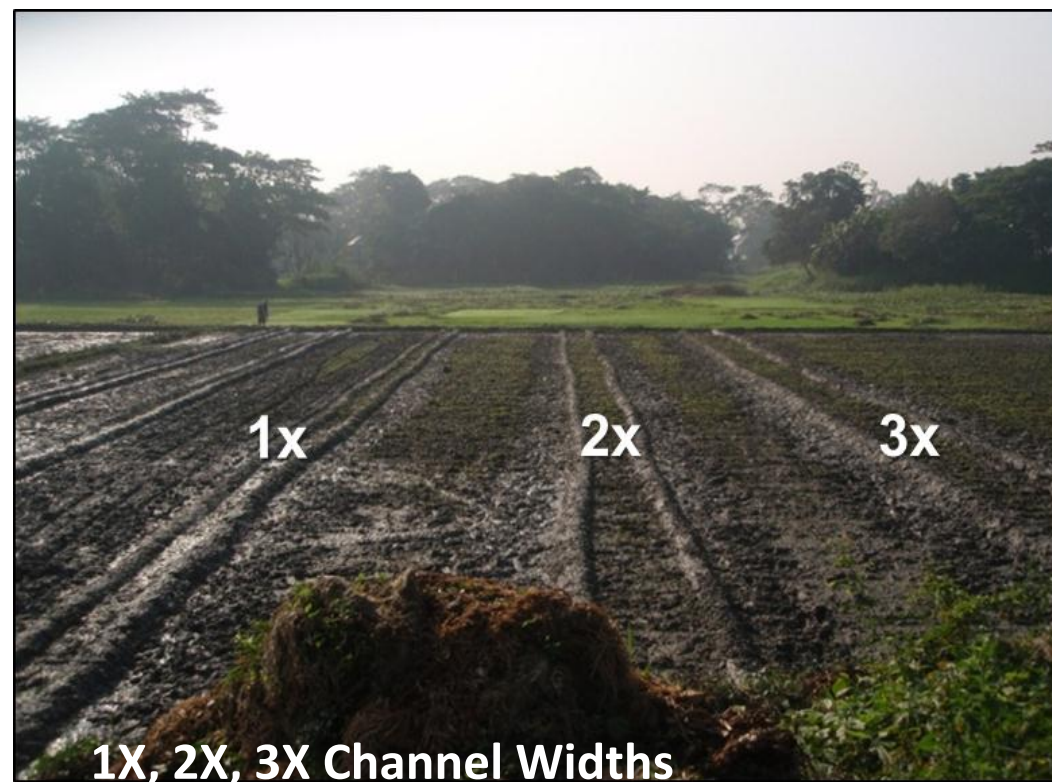
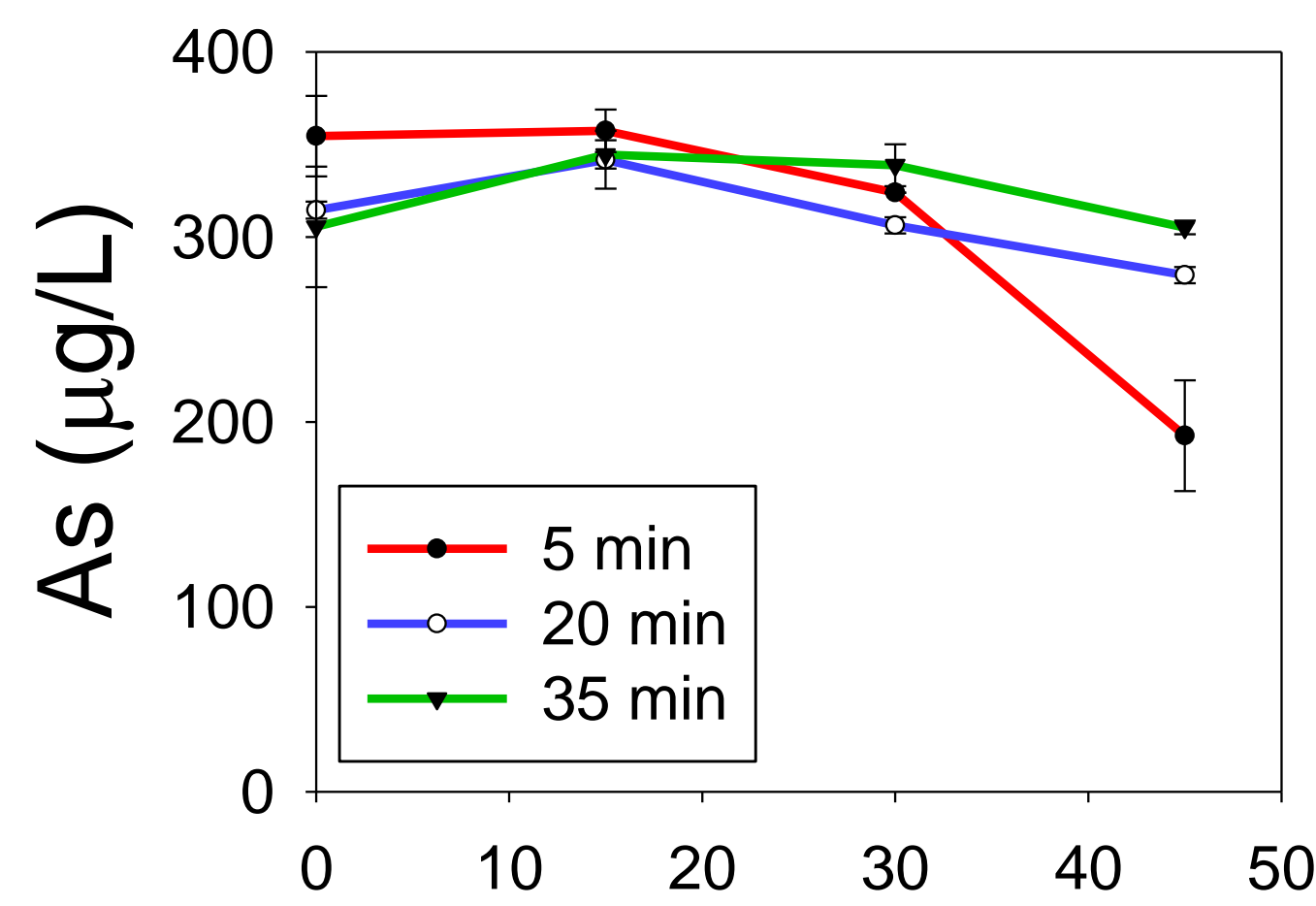
Figure 2. Decreases in arsenic concentrations along tarp-lined channels show evidence of arsenic removal from solution by co-precipitation. By lining a channel with a plastic tarp, we prevented arsenic adsorption to soil. Therefore, we attribute observed decreases in arsenic concentrations along the wetting front to co-precipitation. At the full hydraulic profile (later time points), the ratio atmospheric contact to water volume significantly decreases, decreasing oxygenation and therefore decreasing co-precipitation.



Soil Lined

Tarp Lined

3x Channel Width



1X, 2X, 3X Channel Widths

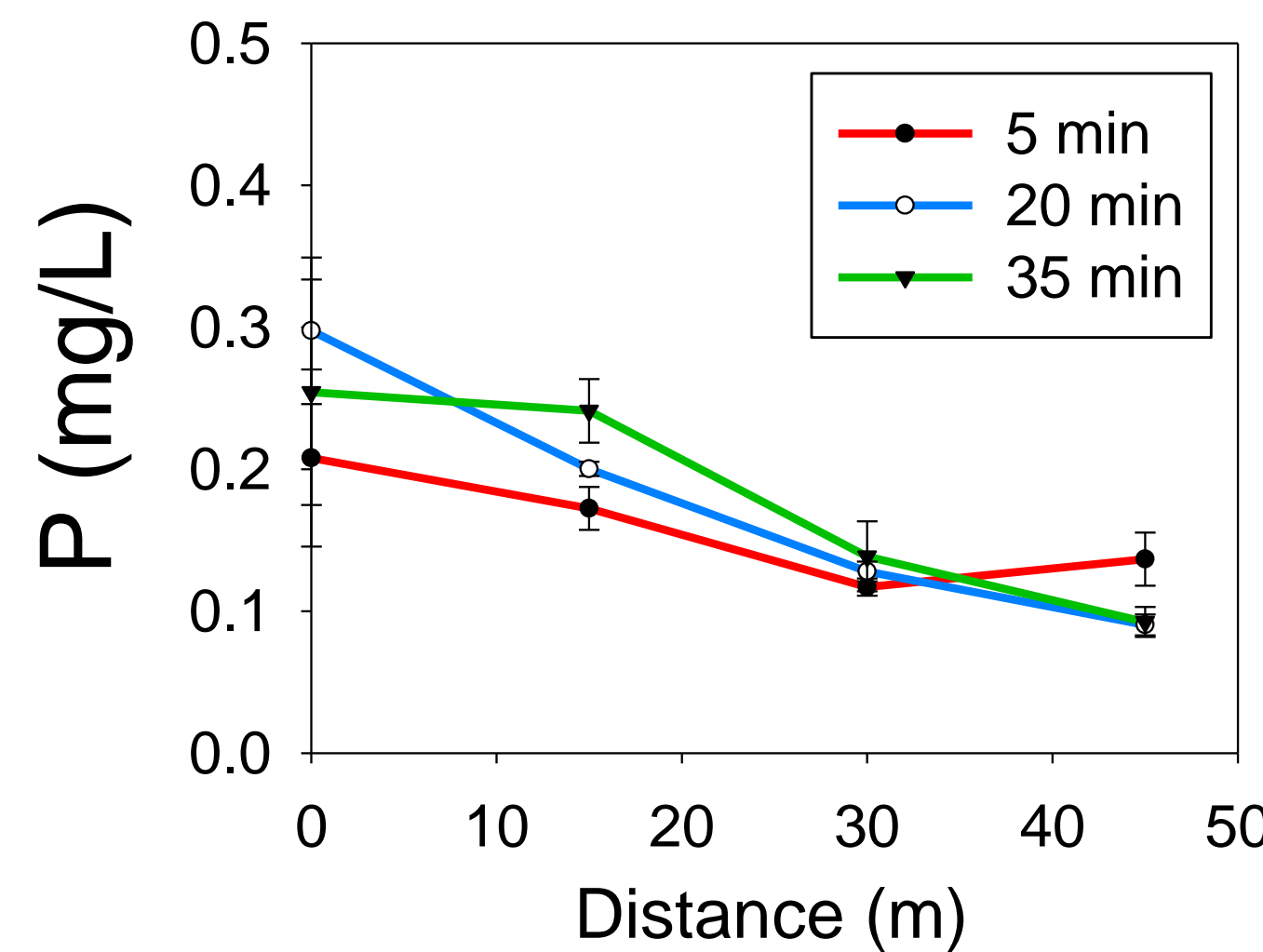


Figure 3. Increased (3x) channel widths and irrigation water residence times highlight the sorption affinity for phosphorus. The decrease in P concentration is much greater than the decrease in As concentration indicating a sorption affinity for P over As; this affinity seems to disappear between 30m and 45m. In the 3x channel we observe a much slower flow than in the regular width channel, increasing P removal along the channel. Once P concentrations flatten, As is removed from solution, perhaps due to oxidation of the less competitive initial species As(III) to more competitive As(V).

Channel Length

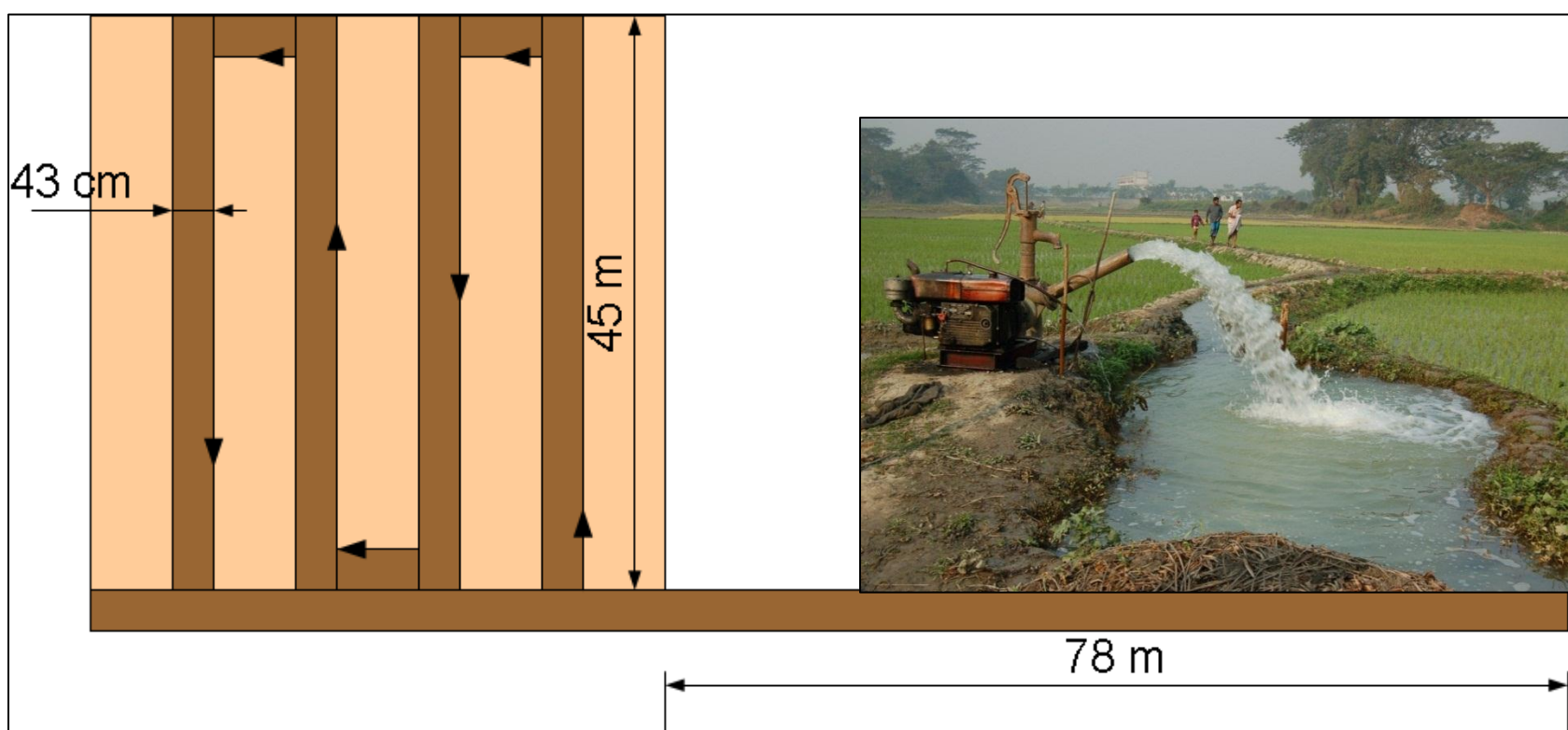
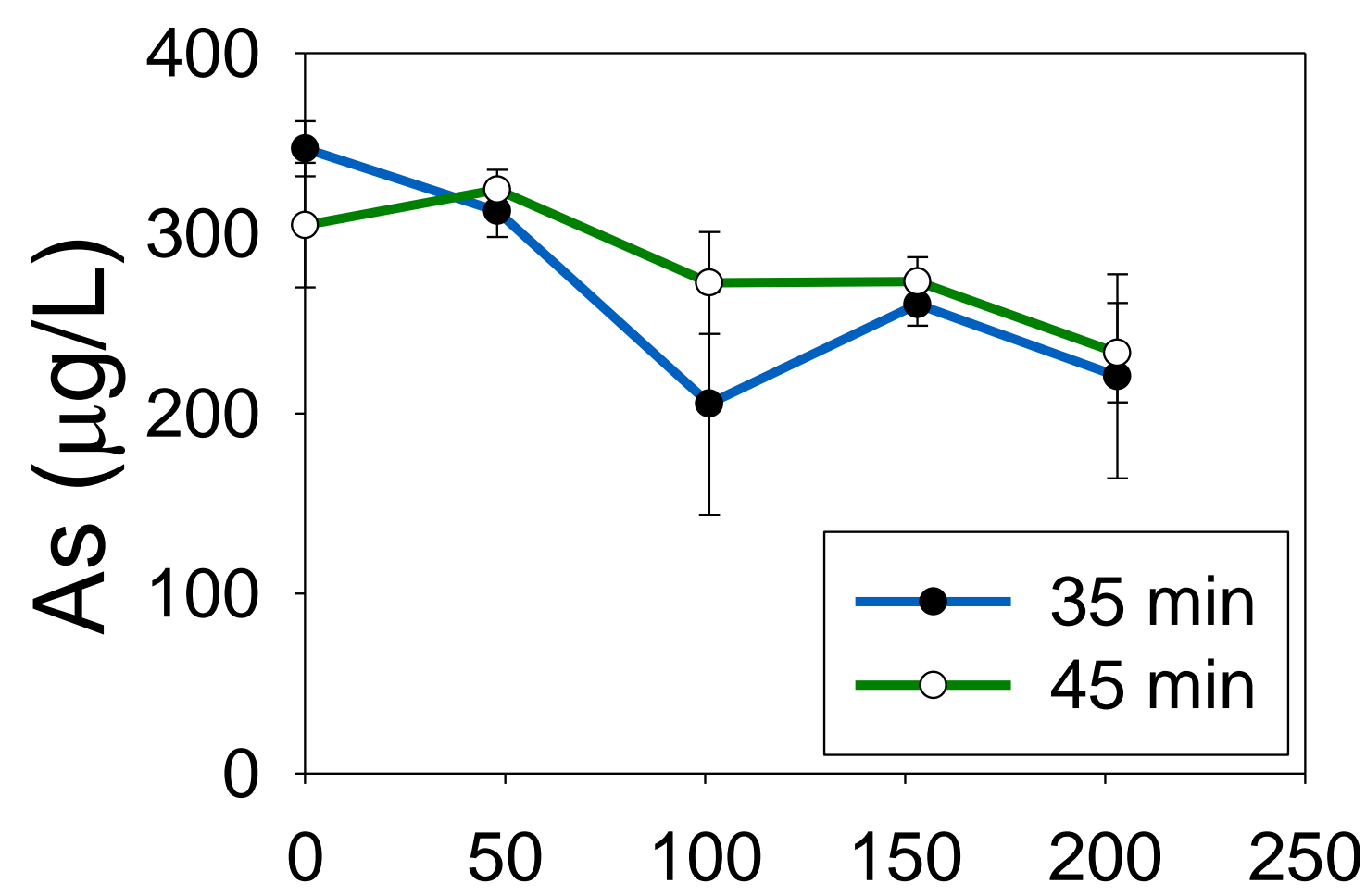
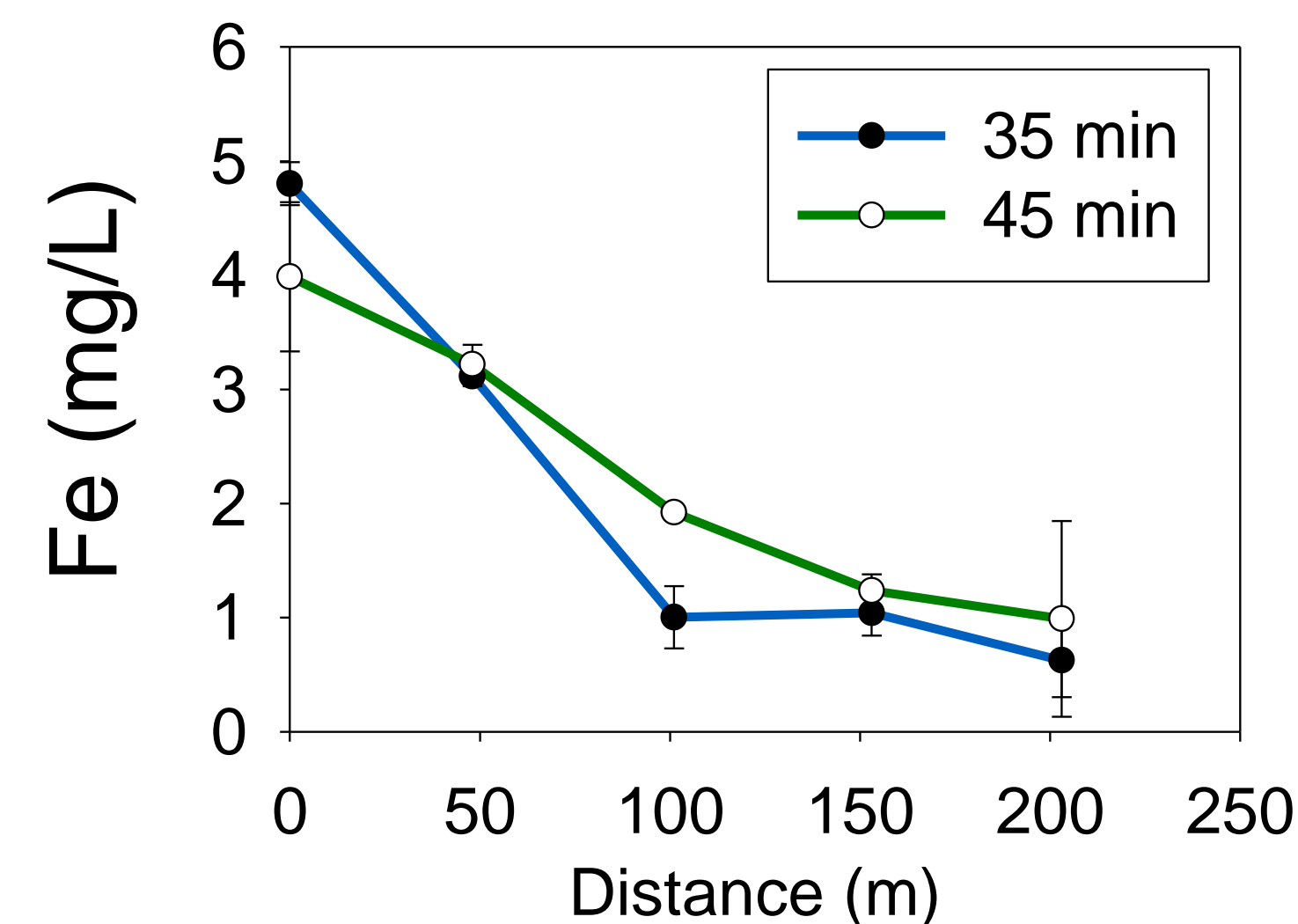


Figure 4. Arsenic concentrations decrease at later time points if channel length is increased. Increasing the flow path to 200 m shows continued decreases in arsenic concentrations along channel length. The increased contact with both sorption sites and the atmosphere results in more As removal. At 200 m, Fe concentrations approach 0 indicating that potential for co-precipitation is maxed out . Further removal of arsenic would likely result only from sorption to mineral surfaces, including soil and suspended Fe particles.



CONCLUSIONS & IMPLICATIONS

- Arsenic concentrations in flowing irrigation water are governed by a host of processes (Figure 5)
- Arsenic concentrations are lowest in the wetting front, where the ratios of atmospheric and soil contact to water volume are the greatest
- Iron concentrations decrease along channel lengths as iron oxidizes and precipitates. These precipitates remove arsenic from solution via sorption and co-precipitation
- Phosphorus concentrations decrease much more than arsenic concentrations, highlighting that well water composition is very important to the amount of arsenic that can be removed from a flowing channel
- To minimize As loading to rice field soils via irrigation channel construction:
 - Maximize oxygenation to enhance As and Fe oxidation
 - Increase residence time in channels
 - Lengthen channels
 - Limit the depth of flowing water
 - Trap particles to remove suspended As-bearing precipitates

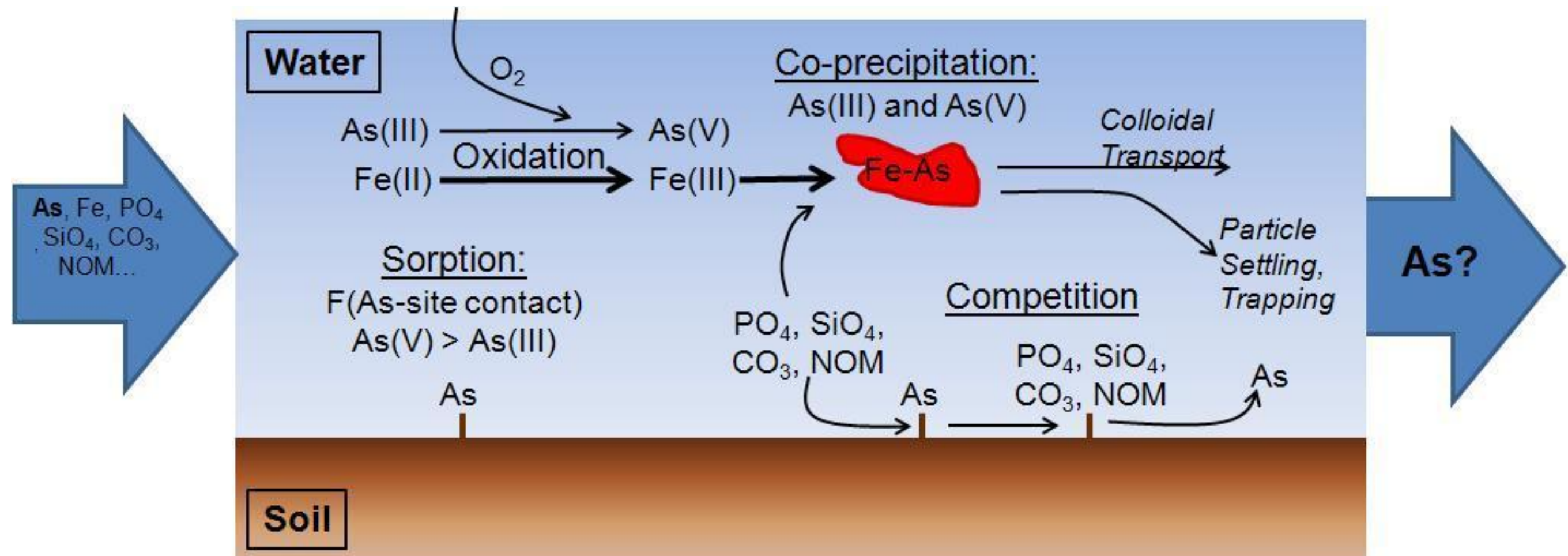


Figure 5. Conceptual model of the processes influencing arsenic removal from flowing irrigation water. Sorption and co-precipitation are two mechanisms that remove arsenic from solution. Sorption of arsenic to soils is controlled by arsenic speciation, as arsenate (As(V)) sorbs preferentially to arsenite (As(III)). Competition from other anions (e.g. phosphate, silicate, and carbonate) may limit arsenic sorption. When exposed to the air, dissolved As and Fe oxidize. Changing flow length and channel shape affects the number of adsorption sites contacted by the flowing water as well as the amount of O₂ that will dissolve into channel flow. Precipitates that form will gradually settle to the channel bottom, and the rate at which they settle will be affected by flow path shape as well as the velocity of flow.

FUTURE WORK

- Increase oxygenation of water through riffles and grade control structures
- Establish optimum channel lengths with respect to land area to maximize both rice production and As removal
- Investigate slower flow paths – via pumping rates and grade control structures – to increase time As and competing ion adsorption
- Define how much As(III) is converted to As (V) over the course of a channel
- Determine chemical limits on arsenic adsorption to rice field soils and the potential for arsenic desorption

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