STUDY OF COAGULATION AND SETTLING PROCESSES FOR IMPLEMENTATION IN NEPAL

BY

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ENG

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Abstract

This paper studies coagulation and settling within the context of water treatment alternatives in Nepal. In January 2000, a team of MIT Masters of Engineering students travelled to Kathmandu, Nepal, to investigate the effectiveness of three potential potable water treatment processes: coagulation, filtration, and disinfection, for use separately and in combination. This paper focuses on the coagulation study as applied to point-of-use (POU) household water treatment for use in rural areas of Nepal and to centralized water treatment plants in Kathmandu, which currently use coagulation as one unit process.

Coagulation and settling experiments using mechanized jar test experiments were performed on locally available alum from Nepal, alum from the United States, and Ferric Chloride from the United States, to determine a dosage and mixing regime that would yield optimum removal of turbidity. These doses were found to be 40 mg/l, 30 mg/l, and 20 mg/l for Nepal alum, U.S. alum, and U.S. $FeCl_3$, respectively. This optimum dosage was then applied to POU treatment in the form of manual coagulation (coagulation by hand) in order to qualify its effectiveness. Experiments with manual coagulation indicate that although POU coagulation was somewhat successful in reducing color and turbidity, color and turbidity were not reduced to concentrations suitable for disinfection. Conclusions on optimum coagulant dosage were then applied to point-of-distribution (POD) treatment systems that possess the capability to implement measured coagulant doses including the Mahankal and Bansbari water treatment plants.

Thesis Supervisor: Susan Murcott
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I am truly grateful for the generous donation of the jar stirring equipment arranged by Mr. Wes Skaperdis of Phipps & Bird. I would like to thank those at the Nepal Water Supply Corporation's Central Laboratory in Kirtipur and Mr. Dili Bajracharya, who arranged lab space where my fellow team members and I could conduct our studies. I would also like to thank Maheshwor Kafle, who helped me find resources of information, lab supplies, and answered my many questions. Additional thanks are extended to my advisor, Susan Murcott, and the department for providing funding so that such a trip would be possible.

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1.0 Introduction

Nepal has abundant freshwater resources including springs, rivers, and groundwater supplies, however drinking water quality varies greatly. Inaccessibility of safe drinking water is endemic in the densely populated regions. Only 59% of Nepal's population have access to safe drinking water.[1] Many settlements and households do not have access to piped water. In urban areas such as the capital of Kathmandu, access to piped water is available to 57% of urban households.[2] Table 1 shows the distribution of households by source of drinking water.

TABLE 1-1: DISTRIBUTION OF HOUSEHOLDS BY SOURCE OF DRINKING WATER, 1996[2]

Sources of drinking water	Rural	Urban
Piped water	29.1	57.4
Well water	7.0	8.7
Hand pump	33.3	27.3
Spring water	20.8	0.0
River/stream	7.6	3.3
Stone tap	1.6	1.8
Other	1.7	1.5

There are three distinct geographic regions in Nepal: the southern plains, the foothills, and the Himalayas. The plains region, called the Terai, is densely populated and has heavy industrial and agricultural activity. In the Terai, much of the drinking water comes from groundwater wells. The foothills lie between the plains and the mountains. This region is also densely populated and contains most of the major cities including Kathmandu. Drinking water sources in the foothills include both surface and groundwater. The population of the

[1] Nepal at a Glance. The World Bank Group. September 1999. <http://www.worldbank.org/data/countrydata/aag/npl_aag.pdf>
[2] United Nations Development Programme (UNDP), Nepal Human Development Report 1998

mountainous Himalayan region is sparse and often migratory. In this region, drinking water comes mostly from surface water sources.

Water in the high mountainous Himalayan regions, raw surface water is found to be of excellent quality and little or no further treatment is necessary to prepare it for drinking. In the foothills and plains, however, urban and industrial runoff impairs surface water quality and, not surprisingly, water is found to be both highly turbid and microbiologically contaminated. Groundwater in these regions, although of better quality than surface water, is also found to be turbid and microbiologically unfit for drinking. According to authorities at the Nepal Water Supply Corporation, water quality is especially poor during the rainy season when high levels of rainfall stimulate sediment resuspension, increasing turbidity from 10 NTU (Nephelometric Turbidity Units) in the dry season to as high as 1500 NTU in the rainy season. Even groundwater sources supplied from wells, hand pumps, and stone taps supply water of poor quality that require treatment before consumption.

Based on field investigations and interviews in Nepal during the month of January 2000, Nepalis outside the urban areas of Kathmandu Valley do not treat water before consumption due to a lack of awareness of treatment methods and/or a lack of financial resources to carry out such treatment. Consequently, the only rural Nepalis that consume treated water are those with access to piped-in water treated at the point-of-distribution (POD). From personal experience through field studies, even the quality of this treated water is questionable. This group accounts for only 29%, leaving the remaining 71% in rural areas to obtain drinking water from entirely untreated groundwater and surface water sources.[2] As a result, waterborne diseases are rampant. The development of a point-of-use (POU) water treatment regime would improve the quality of drinking water for those who must rely on groundwater or surface water sources. Because POD treated water is of questionable and unpredictable quality, POU treatment would also improve water quality for those who have access to POD-treated water and serve as an additional barrier against disease above and beyond the levels of treatment currently supplied.

In traditional POD treatment systems, conventional water treatment plants can be simplified to a three-phase process comprised of coagulation and settling, filtration, and disinfection. POU treatment is adapted from this simplification of POD treatment processes. Hence, coagulation and settling represents the first step in a three-phase process of POU treatment. Compared to filters used in the second phase of treatment, costs in the implementation of the coagulation phase are minimal. Successful coagulation and settling processes may reduce if not eliminate the need for filters in the second phase of treatment and improve accessibility to better quality water by reducing the cost of treatment.

Because even water piped into Nepali households is currently of poor quality, the results from this study will be applied to existing water treatment plants to improve POD-treated water by optimizing dosage and frequency of in-stream alum addition. The focus of this thesis is threefold:

1. Optimum Coagulant Dose: Experiments were performed to determine the optimum dose of common coagulants such as alum and ferric chloride ($FeCl_3$) needed to achieve maximum turbidity removal. Common coagulants such as were used.
2. Manual Coagulation: The conclusions of dosage necessary to achieve optimum turbidity removal were applied to POU treatment systems to determine the feasibility for implementation in Nepal as a means of providing low cost treatment alternatives. Specifically, we examined the success of manual coagulation and determined the suitability of replacing filters with an inexpensive coagulation step.

3. Application of Bench-Scale Testing Results to Full-Plant Coagulation Processes: In POD systems, water treatment plants were examined to determine how coagulation and settling data obtained through laboratory experiments could be applied to improve effluent quality. Specifically, existing facilities at water treatment plants in the Kathmandu Valley were examined to determine the capacity of plants to implement coagulation and settling treatment.

1.1 Coagulation and Settling as Pretreatment

Coagulation and settling play a major role in the preliminary phase of drinking water treatment by reducing or eliminating impurities such as turbidity, bacteria, algae, color, organic compounds, oxidized iron and manganese, calcium carbonate, and clay particles (Culp et al). When used as a pretreatment to filtration and disinfection in POU or POD systems, they greatly increase the effectiveness of the latter processes by reducing or eliminating suspended particles that would otherwise clog filters or impair disinfection, thereby dramatically minimizing the risk of waterborne diseases. A low-cost alternative to manufactured treatment devices would improve access to better water quality. During the rainy season in Nepal, when surface water turbidity is orders of magnitude worse than during the dry season, an affordable means of POU treatment is extremely important. Because visible impurities in water are comprised mainly of suspended particles with roughly the same density as water, they do not settle out of the system independently. Chemical coagulants are added to aid in the aggregation of smaller particles into larger ones that will settle to the bottom of the system.

In POU treatment, based on the model of water treatment plants, water treatment can be simplified into three phases: coagulation and settling, filtration, and disinfection. Coagulation and settling can serve as a single step to improve water quality or it can act as pretreatment to remove most turbidity and impurities from raw water. Filters are then able to function more efficiently to remove remaining turbidity, color, and various other parameters. With reduction of turbidity and suspended particles, filter effluent is then translucent enough to achieve successful removal of mircroorganisms during the disinfection phase. Unless coagulation and settling is capable of extensive color and turbidity removal, filtration is still required. Under circumstances in which filters are unavailable, coagulation and settling as pretreatment to disinfection is the next best option. Small household quantities of alum involved in POU treatment make manual coagulation (coagulation by hand), a possible option where distribution of clean water is not possible. This thesis will examine the effectiveness of manual coagulation and its applications in POU treatment.

In water treatment plants, the coagulant is dosed upstream of the flocculation and/or sedimentation basin under a turbulent flow to ensure adequate contact with suspended particles. The turbulent flow path induced in the flocculation basin ensures adequate contact between destabilized particles and promotes floc formation. Detention time in sedimentation basins allow flocculated particles to settle out of the system.

1.2 Current Uses of Coagulation in POU and POD Treatment in Nepal

Based on field investigations and interviews conducted in Nepal during the month of January 2000, the MIT Nepal Water Project team learned that the extent to which drinking water is treated before consumption is largely a factor of level of education and financial status. Only the middle to upper class Nepalis, generally found in urban areas, are able to afford pretreatment, such as filters, that reduce the risk of waterborne diseases. As a further precaution against disease, they often boil filtered water. However, in rural areas, where 80% of Nepalis live, water receives little, if any, treatment before consumption. Many are either unaware of household water treatment methods or cannot afford the cost of water filters or other types of manufactured treatment. The only treatment is sedimentation that occurs unintentionally while collected water sits in *gagros*, large family-size containers, awaiting consumption. However, the resistance of suspended particles to settle without an added coagulant limits treatment efficiency by this means. Despite long periods of settling time, water remains turbid. Although unused in Nepal at present, coagulation and settling is a potentially more affordable means of POU treatment that would enable even poor rural villagers access to safer water.

There are six water treatment plants in the Kathmandu Valley; they apply coagulation in varying degrees of operational precision ranging from in-stream dissolution of solid alum to more sophisticated treatment using regulated dosages of dissolved alum that flow into flocculation tanks before proceeding to sedimentation basins. Because iron salts for coagulation are difficult to obtain in large quantities in Nepal, and consequently expensive, alum from India is the only coagulant currently used. In the older water treatment plants, the coagulant is dosed by placing a large chunk of alum weighing approximately 10-15 lbs in the influent stream, allowing it to dissolve into the water stream as flow empties into sedimentation basins. The newer and more sophisticated plants have flocculation basins that precede sedimentation basins. At the influent of the flocculation basins, a regulated dose of alum in solution is injected into the stream. Chemically treated water then flocculates and settles before entering the filtration phase of treatment. The coagulation studies reported in this thesis are intended to help optimize dosage and frequency of in-stream alum additions in both operationally simple and sophisticated plants.

2.0 Theories in Science and Applications

2.1 Scientific Theories

Coagulation is the electrochemical process of aggregating small particles into larger particles or "flocs" that settle more rapidly than individual particles due to their increased weight. It is also the most common first step in water treatment prior to treatment whereby the removal of impure particulates can be achieved. In this process, coagulants are added to turbid water in order to destabilize particles and reduce inter-particle repulsion forces. Destabilization increases the tendency of particles to coalesce on contact, resulting in heavier agglomerated particles. The heavier particles will then settle out of solution.

There are two main theories that attempt explain the transformation between stable and unstable particles:

The physical theory is based on the presence of electrical double layers surrounding a particle and counterion adsorption. It proposes that a reduction in electrostatic forces, such as the zeta potential, is responsible for destabilization (Culp et al).

The chemical theory assumes that suspended particles, or colloids, are aggregates of chemical structural units. Therefore, specific chemical reactions between colloidal particle and chemical coagulant are responsible for destabilization (Culp).

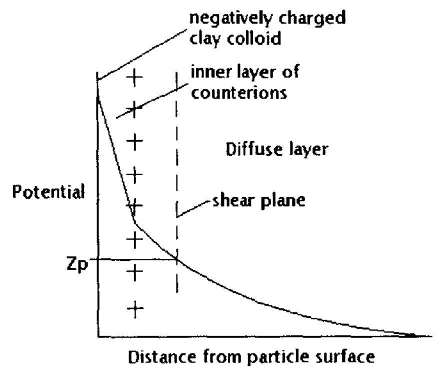

FIGURE 2-1: RELATIONSHIP BETWEEN ZETA POTENTIAL AND DISTANCE FROM PARTICLE SURFACE

In the physical theory, the electrical double layer consists of ions that counterbalance charges developing at particle-water interface. The ions surround a colloidal particle to preserve its electroneutrality. The inner layer of counterions are a compact layer on the colloid surface while the remaining counterions make up a diffuse layer extending into the solution. At the plane of shear within the diffuse layer, the zeta potential is measured. The zeta potential's magnitude describes the colloidal particle stability. Low potentials correlate to easily coagulated unstable systems while high potentials relate to strong forces of separation and stable, difficult to coagulate systems (Culp). See Figure 2-1 for a visual schematic of the relationship between zeta potential and distance from particle surface (van Olphen, 1977).

2.2 Coagulant Selection Criteria

Effective coagulation is a function of many factors, the complete list of which is detailed in Table 2-1.[3] Some of the most important factors influencing the effectiveness of coagulation are coagulant dosage and mixing times. There is a range of optimum dosages for a coagulant at which maximum settling and removal of suspended particles is most efficiently and effectively achieved. Below this range, the amount of coagulant added is insufficient to adequately destabilize the particles. Above this range, the coagulant essentially serves as a chemical coating which re-stabilizes the particle. The window of acceptable dosages varies with every coagulant and with many of these factors, making some less sensitive to imprecisely measured dosages. Similarly, there is an optimum range of mixing times that most effectively aids removal of particulate matter. There are typically three phases of mixing in a coagulation process: rapid mix, gentle mix, and no mix. The rapid mixing phase is a short period of extremely turbulent mixing that allows coagulants contact with suspended particles. The next phase is flocculation. It is characterized by gentle mixing and allows destabilized particles to agglomerate together into larger particles. The final phase consists of no mixing. It allows flocculated particles to settle out of the system. Insufficient periods of gentle mixing result in poor agglomeration of particles. Prolonged agitation periods, however, lead to ruptures in floc fragments and dis-agglomeration of particles (Culp).

TABLE 2-1: FACTORS AFFECTING COAGULATION[3]

Coagulant Characteristics	Physical Characteristics	Raw Water Characteristics
• Coagulant type • Coagulant dose • Proper solution makeup and dilution • Proper coagulant age	• Settling time • Mixing intensity • Mixing time • Coagulant addition point • Proper coagulant feed	• Suspended solids • Temperature • pH • Alkalinity • Presence of microorganisms and other colloidal species • Ionic constituents (sulfate, fluoride, sodium, etc.)

[3] Murcott, Susan, "Chemically Enhanced Primary Treatment"

Coagulation is also affected by water-based variables such as pH and alkalinity (Hudson). Acidic waters contribute to ease of color removal while alkaline waters show greater response to turbidity removal (American Water Works Association). Because every raw water can be different, field-testing can determined the effectiveness of specific coagulation and settling regimes on a given water.

To improve the effectiveness of coagulants, coagulant aids may also be added to the mixture. Coagulant aids consist of either synthetic or natural materials that improve the settling characteristics and toughness of the flocculated particles, which in turn permit shorter sedimentation periods and higher rates of filtration. Moreover, they may also significantly reduce the required dosage of primary coagulants, thereby reducing costs of treatment. Due to need for importation, precise dosages, and higher costs, synthetic coagulant aids are not feasible for use in developing countries such as Nepal (Schulz and Okun).

Natural coagulant aids are divided into two categories: adsorbent-weighting agents and natural polyelectrolytes. Adsorbents-weighting agents consist of powdered calcium carbonate, bentonitic clays, fuller's earth clay, and other adsorptive clays. They assist in the coagulation of waters containing high color or low turbidity by providing additional suspended matter to the water upon which flocs can form. Specifically, dosages in the range of 10 to 50 mg/l may result in good floc formation, improved removal of color and organic matter, and a broadening of the pH range for effective coagulation (Schulz). In low turbidity waters of less than 10 NTU, addition of adsorptive clays may reduce the dosage of alum required. Calcium carbonate dosages of approximately 20 mg/l can also be added to supply alkalinity. Qualities such as ease of storage, handling, and application make calcium carbonate especially accessible for treatment purposes (Schulz and Okun).

Polyelectrolyte coagulant aids have structures consisting of repeating units of small molecular weight. These units form large molecules of colloidal size that carry electrical charges or ionizable groups that provide bonding surfaces for the flocs. Natural polyelectrolytes are derived from sources such as the seeds of the following plants: Nirmali tree, Tamarind tree, Guar plant, Red Sorella plant, Fenugreek, and Lentils. In addition, seeds from the plant Moringa Oleifera and Chitosan, a product typically derived from the waste of shellfish, have also shown to be extremely effective, with results rivaling those achieved with conventional alum treatment (Schulz and Okun).

3.0 Applications of Coagulation and Settling in POU and POD Treatment

3.1 Case Study of Successful Application of Coagulation in POU Treatment Using Coagulation in Sudan

Traditional applications of coagulation and settling in POU treatment by have been documented in rural areas of Africa such as Egypt, northern Sudan, southern Tunisia, Lesotho, and Orange River District (Jahn, AWWA 1988). Like Nepal, these countries are economically unable to provide clean water to rural populations. Traditional methods of coagulation employed the use of locally available natural materials such as kernels from plants such as almonds, apricots, peaches from the genus *Prunus* (Jahn). These methods, however, have shown limited effectiveness. The cost of traditional western coagulants such as alum can escalate to as much as seven times the initial cost during the transportation of goods from sources in Europe to consumer points in Africa (Folkard, 1986).

In Sudan, along the Nile River Valley, rural women are acquainted with basic POU coagulation methods with local materials, as this is a traditional method of water purification (Gupta and Chaudhuri). Bentonite clay or local plant materials are crushed in small bowls with water before being poured into turbid water as a method of treatment (Olsen, 1985). Although Olsen does not indicate exactly what species of local plant materials were used, other studies have found the cited the use of seeds from the Papilionacaeae family from the following genera: Pisum, Lens, Lablab, Arachis, and Lapinus. However, these plants are known to be weak water clarifiers (Jahn). Cultures that can trace such water treatment methods in their own traditions are much more open to new variations of such treatment because the concept, already engrained in their culture, is familiar and accessible. Field interviews in Nepal, conducted as a part of this

POU study, suggest that Nepal does not have an indigenous tradition of coagulation by traditional means of small-scale water treatment even though Nepal borders India and China, both of which have a traditional household-scale coagulation practice.

Jahn's studies focused on the application of natural coagulants such as Moringa Oleifera in Sudan. Although these plants were already being used as coagulants, Jahn developed optimum dosages for better turbidity removal efficiencies. After standardizing this dosage so that it would be applicable under different factors affecting coagulation such as water conditions and local variations between different strands of Moringa Oleifera plant family, dosage instructions were disseminated (Jahn). Teachers or others in the community who have been trained in this procedure prepare dosage instructions based on weekly jar tests and then disseminate it to local people. The method by which dosing information for natural coagulants was integrated into indigenous cultures in Jahn's study is of great interest because her methods may be used as a model around which recommendations for distribution of possible coagulants in Nepal could be structured.

The Moringa Oleifera seeds were not native to Sudan and the other areas currently using the seeds in treatment (Jahn). In fact, the origins can be traced to sub-Himalayan tracts of India but due to the resilient nature of the Moringa crop, it has since been successfully introduced in most subtropical and several subtropical climates (Jahn).

The Moringa Oleifera was originally introduced into Sudan as an ornamental tree when the British took over in 1898. Since its introduction by the British, Sudanese women have discovered its uses as a natural coagulant, replacing former plant species with this more efficient one. Successful education and distribution systems were essential in ensuring its viability in effective water treatment.

Due to the inherently irregular nature of hand coagulation, a standard and consistent speed of mixing during each phase is difficult to achieve. Jahn notes that listening to a metronome record or chanting set phrases in the indigenous language while stirring can help standardize mixing speeds by providing a rhythm to which the repetitive stirring can be applied. For example, to achieve a mixing rate of 18-20 rpm, a possible chant could consist of four simple two-syllable words. An entire rotation would be covered by one word while half a rotation would be covered by one syllable. An example set in English to the phase "Treated water healthy people" would be the following (Jahn):

Ted Trea- ter wa- thy heal- ple peo-

Although Jahn notes that this technique can be especially helpful during the slow stirring phase, it may also be applicable during the rapid mix phase. Regularity of mixing speed is more essential during the 10 minutes of slow mixing than it is during the 1 minute of rapid mix because of greater risk of floc breakup during slow mixing.

Lessons can be learned from the POU treatment regimes implemented in Africa and Asia for applications in Nepal. The distribution of non-local Moringa Oleifera seeds serves as a model for the distribution of alum. The training of locals to correctly use the coagulant in POU treatment could also apply to the situation in Nepal. And lastly, suggestions to regulate the pace of hand mixing may help limit irregularities inherent in manual processes. Application of this case study will be discussed in detail in the conclusion.

3.2 Large Scale Current Coagulation Processes in Water Treatment Plants

There are six water treatment plants in Kathmandu, of which four use coagulation as part of the treatment process. The four water treatment plants employing coagulation processes consist of Mahankal, Bansbari, Sundarighat, and Balaju, and are oulined in Table 3-1 below. Mahankal and Bansbari, the newest of all the plants, apply dissolved alum in measured doses while Sundarighat and Balaju apply solid block alum to in-stream flows. Information was obtained from field visits in January 2000 and interviews with authorities at the Nepal Water Supply Corporation to provide information on existing facilities at these treatment plants.

TABLE 3-1: COAGULATION PROCESSES IN TREATMENT PLANTS

Plant	**Flow (M l/d)**		**Coagulation Facility**			**Settling**
	GW	SW	Solid	Solution (measured dose)	Flocculation Basins	
Mahankal	28	8		X	X	X
Bansbari	14	8		X		X
Sundarighat	4		X			X
Balaju	300				Offline	Offline
Expected - late 2000	300			X	X	X

3.2.1 Mahankal Water Treatment Plant

As well as being the best maintained water treatment facility in Nepal, the Mahankal water treatment plant is also the largest and most well-designed. Built around 1994, it treats a flow rate of 36 million liters per day (M l/d), and accounts for roughly 60% of all treated water. Although entirely operated and maintained by the Nepal Water Supply Corporation (NWSC), the Nepali government agency responsible for urban area water supply and treatment, the design, substantial financing, and construction were undertaken by the Japanese government. Approximately 28 M l/d of Mahankal's raw water source is surface water from the Bagmati River. The remaining 8 M l/d of flow is groundwater supplied from tube wells in various locations such as the Manohara well fields.

Raw water enters into the treatment plant and is directed into one of four trains of flow. Groundwater supplies the first train and surface water supplies the remaining three trains. The method and extent of treatment applied depends on the source of water. Water treatment consists of alum coagulation, a downflow sand filter, and finally, disinfection with bleaching powder. The coagulation and flocculation process at the Mahankal plant is, by far, the most advanced of all treatment plants in Nepal. The Mahankal plant is the only facility in Nepal to employ a flocculation basin to assist with coagulation and settling processes. After a dose of dissolved alum in 10% solution, water travels through three trains in parallel before discharging into sedimentation basins (See Figure 3-1). At a flow rate of 29 M l/d (330 liters per second) flocculation basins have a detention time of 15 minutes before the water flows into sedimentation basins with detention times of 30 minutes. In the flocculation basin, two trains treat surface water and one train treats groundwater. Each train consists of a series of nine cells with baffle walls (See Figure 3-2) that inflict a winding horizontal and vertical flow path before discharge. The baffle walls in the flocculation basin jut out into the flow stream and measure approximately 8" by 8".

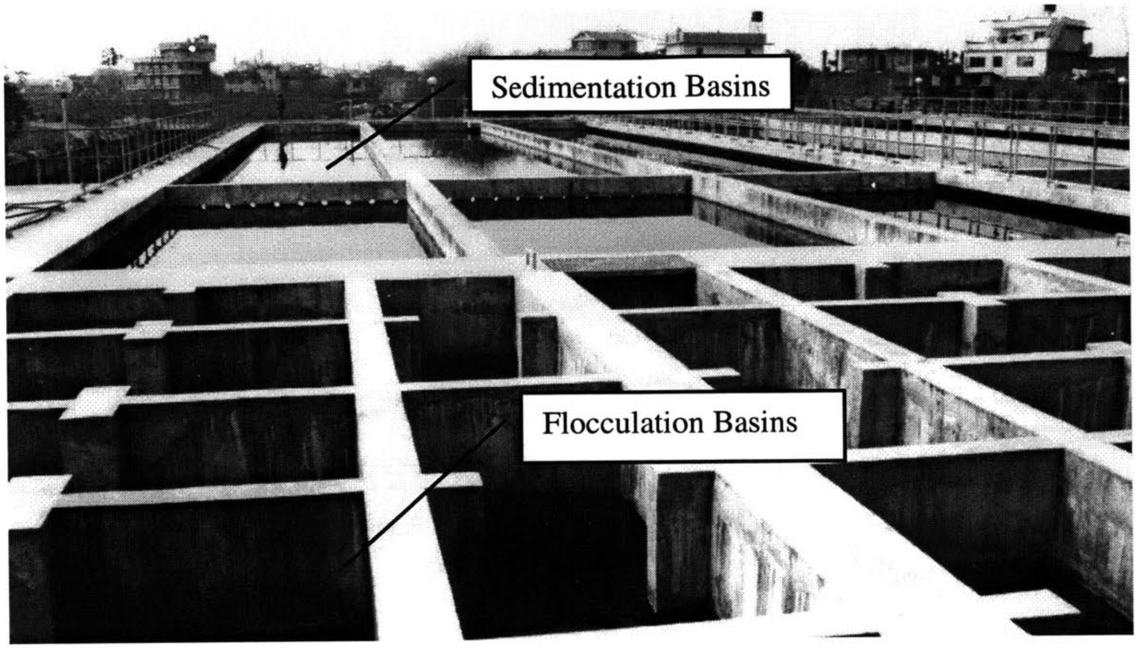

FIGURE 3-1: FLOCCULATION AND SEDIMENTATION BASINS AT MAHANKAL.

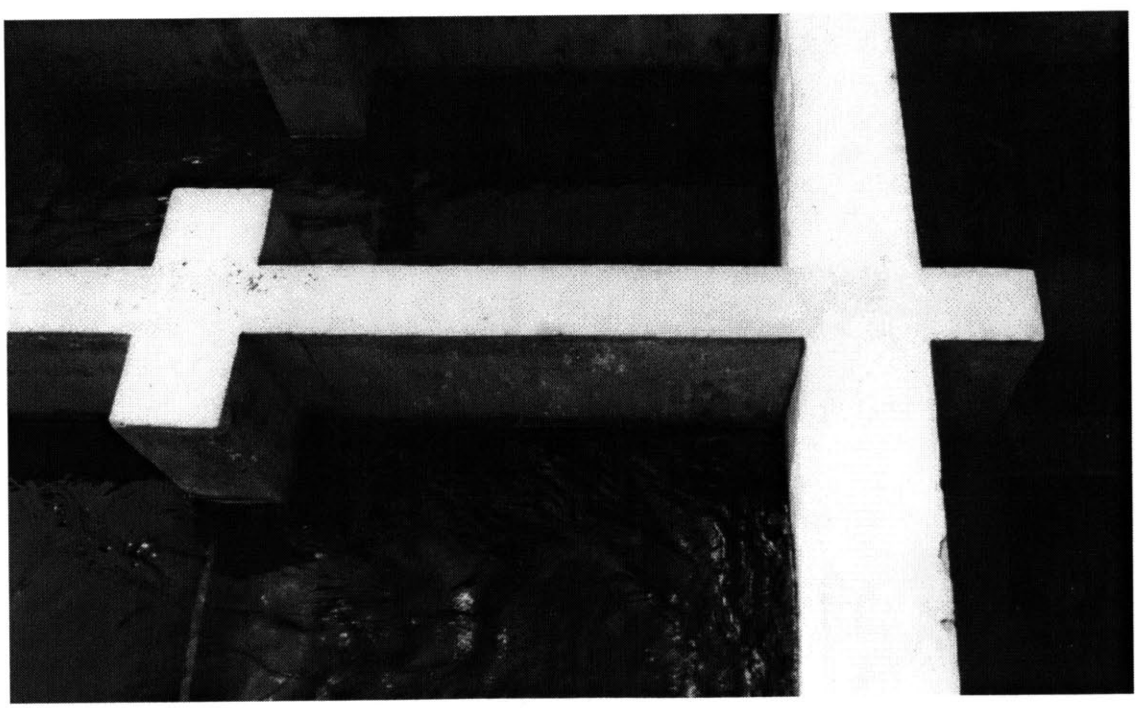

FIGURE 3-2: CLOSEUP OF WALLS IN FLOCCULATION BASIN AT MAHANKAL.

Alum dosage and pH adjustment varies by season and source water, as shown in Table 3-2, a detailed chart indicating recommended dosages of alum, lime, and soda ash. Although the dosage chart indicates a surface water turbidity of 7.5 NTU, this value varies between 10 NTU in the dry season and 1500 NTU in the rainy season. Alum solution is prepared and dosed automatically by the device in Figure 3-3.

TABLE 3-2: ALUM DOSING CHART FOR MAHANKAL.

	Groundwater Flow Trains		**Surface Water Flow Trains**	
	Dry Season	Rainy Season	Dry Season	Rainy Season
Dose (mg/l)	30		20	11
Dose Rate (l/min)	0.21	0.53	0.97	0.53
Turbidity (NTU)	N/A	N/A	7.5	

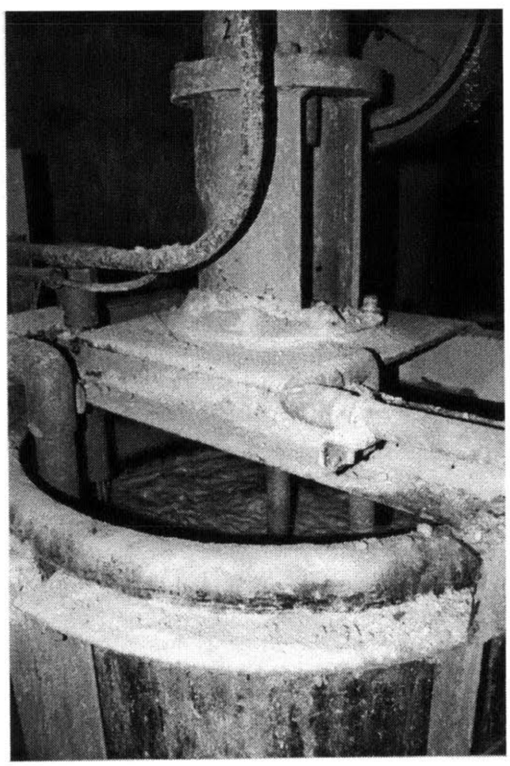

FIGURE 3-3: ALUM SOLUTION MACHINE.

3.2.2 Bansbari Water Treatment Plant

The Bansbari plant, also built by the Japanese in 1995, is similar in design to the Mahankal plant. It handles a surface water flow of 14 M l/d from surface water sources of the Sivapuri Spring and the Bishnumati River. Boring wells supply an additional 8 M l/d for a total average flow of 22 M l/d. Treatment consists of pH adjustment with sodium hydroxide, dissolved alum addition, sand filtration, and disinfection with bleaching powder.

3.2.3 Sundarighat Water Treatment Plant

The Sundarighat plant is the smallest water treatment facility in the Kathmandu valley. Raw water for this facility is taken from the Nakhu River. Treatment consists of in-stream solid alum coagulation, slow sand filter, and bleaching powder chlorination. Alum coagulation is extremely crude and consists of solid blocks of alum that vary in size placed at the point of influent flow into the sedimentation basin. Solid alum dissolved by contact with the influent stream comprises the only dose of coagulant, as there is no other supplementary coagulation dosing method. The frequency of alum dosing is erratic; dosing occurs only when plant operators deem water to be turbid by visual surface inspection of sedimentation basins. Neither quantity nor frequency of dosing is recorded. No flocculation stage exists. Coagulation results are likely inhibited by the neglect of the facility maintenance. During a field visit in January 2000, sludge levels at one end of the sedimentation basin were so high that it was visible from the water surface. Settling efficiencies are greatly reduced in basins already filled with sludge due to the subsurface geometry of collected sludge. Based on measurements taken at the Central Laboratory in Kirtipur, where water supply is piped in from the treated effluent of the Sundarighat plant, treated water turbidity leaving this plant ranged anywhere between 2 NTU to

10 NTU. These variations were observed over the course of one day in the dry season month of January. Monsoon season data was not available.

3.2.4 Balaju Water Treatment Plant

Built in 1935 by the British, the water treatment plant at Balaju is currently a chlorinated reservoir. Although there are onsite flocculation and sedimentation facilities, shown in Figures 3-4 and 3-5, respectively, these facilities are currently offline. According to authorities at the Nepal Water Suppy Corporation, however, the Balaju treatment plant will expand to include pH adjustment, alum coagulation, sedimentation, sand filters, and bleaching powder chlorination by late 2000. At present, the plant handles 300 M l/d and supplies approximately 20% of the treated water in Kathmandu. Boring well and river sources into this plant include Alleey, Bhandare, Baude, Panchmane, and Chhahre.

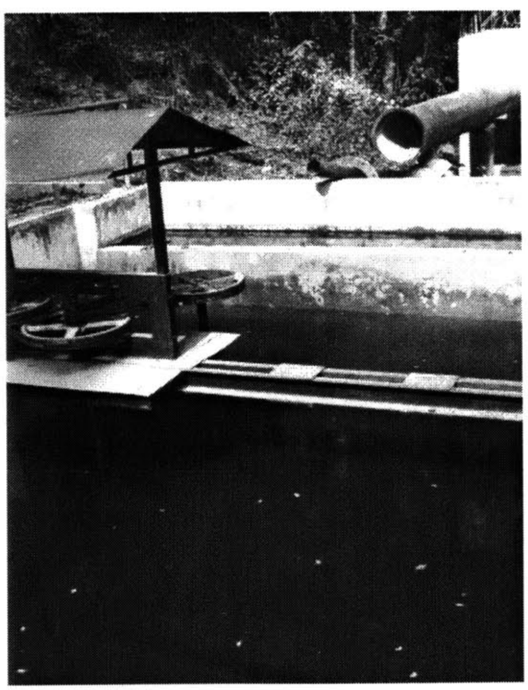

FIGURE 3-4: OFFLINE FLOCCULATION TANKS AT BALAJU.

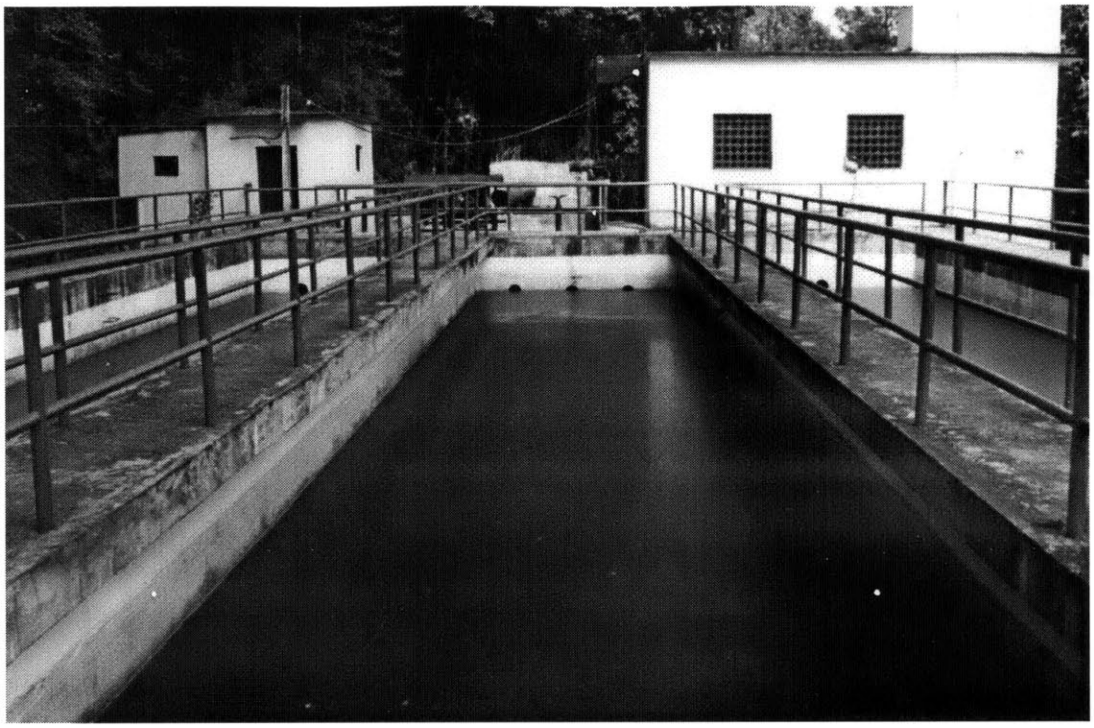

FIGURE 3-5: OFFLINE SEDIMENTATION BASINS AT BALAJU.

4.0 Laboratory Procedures

4.1 Scope of Experiments

Two broad types of coagulation tests were performed: mechanized coagulation using Phipps & Bird jar stirrer and manual coagulation performed by-hand. The mechanized jar stirring tests were used to determine an optimum dosage for maximum turbidity removal. The dosage conclusions from these experiments were then applied to manual coagulation tests using low-technology materials such as commonly available household jugs or buckets and plastic water bottles to determine its effectiveness.

4.2 Equipment

Mechanized coagulation and settling experiments were performed at the Nepal Water Supply Corporation's Central Laboratory in Kirtipur, Nepal using a Phipps & Bird jar stirrer, pictured in Figure 4-1. The jar stirrer, donated by Phipps & Bird, is a PB-700 standard six-paddle model consisting of six stainless steel 1" x 3" paddles spaced six inches apart to accommodate six sample beakers. The motor controls variable speeds between 1-300 rpm of all six paddles simultaneously with the exact speed digitally displayed in the panel. The corners of the square-shaped beakers provide better resistance than round beakers, ensuring greater sample turbulence and thorough mixing. The beakers, shown in Figure 4-2, are constructed with a sampling port located at the 10cm settling-distance level so that jar test samples can be drawn without disturbing settled samples.

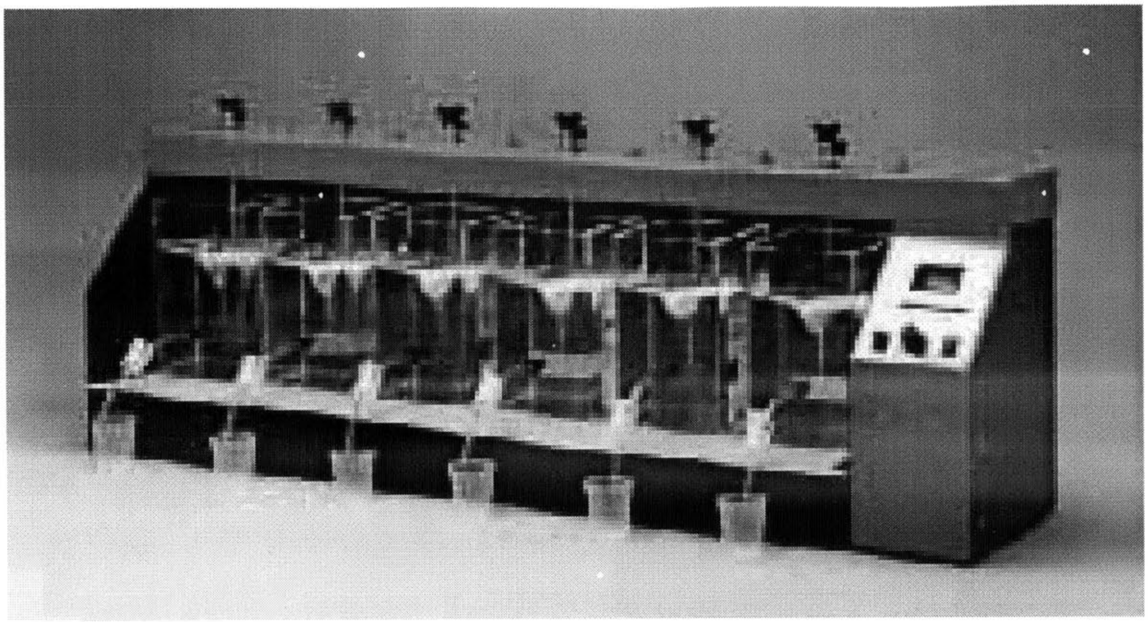

FIGURE 4-1: PHIPPS & BIRD JAR STIRRER

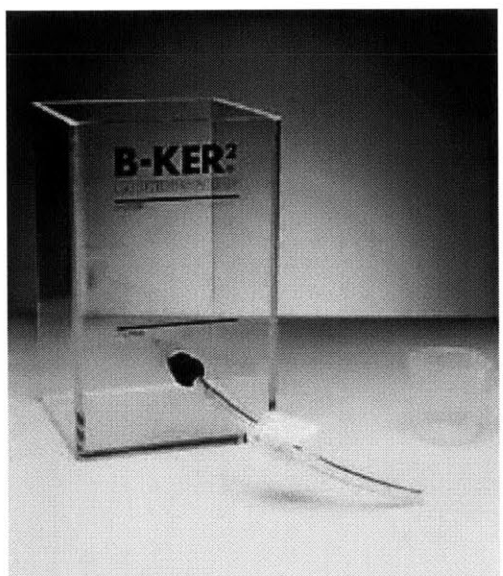

FIGURE 4-2: SAMPLE BEAKER

Turbidity measurements were taken with a Hach portable turbidimeter, Model 2100P.

Manual coagulation experiments were performed with a round 3-liter capacity plastic jug. Stirring was performed with a spatula. A mortar and pestle (See Figure 4-3) was used to grind solid alum into powder form for the making of a 2% alum solution. The body of a 500-ml capacity plastic drinking water bottle was used to measure the appropriate quantity of water to make a 2% stock solution; the cap was used as a measuring instrument (See Figure 4-4). The costs of these supplies are detailed in Appendix A.

Figure 4-3: Mortar and Pestle Pictured with Alum Sample

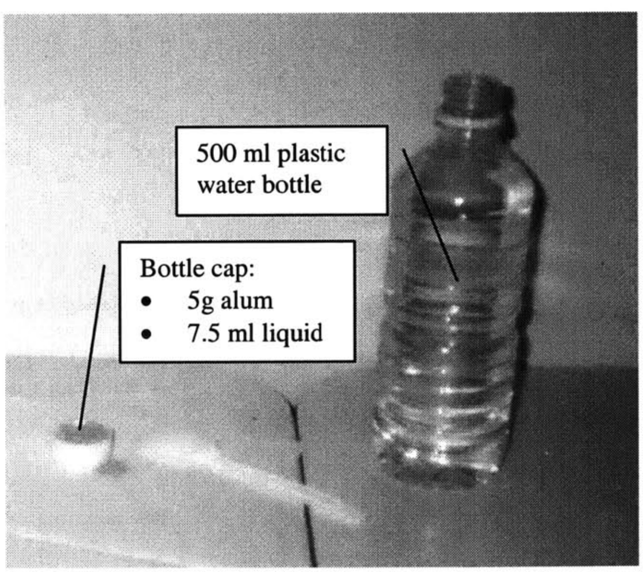

Figure 4-4: Locally available utensils and equivalent measures.

4.3 Chemicals

Chemicals included in the study were two varieties of $FeCl_3$ and three varieties of alum. $FeCl_3$ were two different products, Varennes and Dupont, that were obtained from a single supplier, Eaglebrook, Inc. The experiments focussed on the Varennes brand $FeCl_3$ due to more effective results achieved during preliminary tests. Alum varieties tested include General Alum and Chemical (GAC) brand alum from the United States and locally available bulk alum provided by two different water treatment plants in Kathmandu, Nepal, which came from Indian suppliers. The chemical properties of the chemicals are summarized in Table 4-1.

TABLE 4-1: CHEMICAL PROPERTIES OF COAGULANTS TESTED

Chemical Type	Source (U.S. or Nepal)	Manufacturer or Source	Specific Gravity	Liquid or Solid	% Solids
$FeCl_3$	U.S.	Eaglebrook-Varennes	1.434	Liquid	39.6
$FeCl_3$	U.S.	Eaglebrook-Dupont	1.356	Liquid	33.4
Alum	U.S.	GAC	1.332	Liquid	8.3%
Alum	Nepal	Bansbari	N/A	Solid	N/A
Alum	Nepal	Mahankal	N/A	Solid	N/A

This study tested alum from two separate batches of bulk alum shipments from India, due to the variations in quality and purity found between separate shipments. One shipment was sent over to the Bansbari Water Treatment Plant and the other was sent to the Mahankal Water Treatment Plant (Figure 4-5). Henceforth, these alum varieties will be referred to as Nepal alum, or more specifically as Bansbari alum and Mahankal alum, despite their common Indian origins.

FIGURE 4-5: BULK ALUM STORAGE AT MAHANKAL WATER TREATMENT PLANT.

There are two main types of alum locally available in Nepal: "street" alum and "bulk" alum. Street alum is sold in small quantities by street peddlers to individual consumers to be used as an aftershave for its antiseptic qualities. Bulk alum is sold mainly to large consumers, water treatment facilities being one of them. Although both varieties of alum are essentially the same, bulk alum is purer than its street counterpart. Although street alum also most likely comes from India, the source is unconfirmed.

4.4 Source Water

Source water in mechanized coagulation experiments were performed using non-chlorinated tap water collected at the Nepal Water Supply Corporation's Central Laboratory, which is supplied by treated effluent from the Sundarighat Treatment Plant. The turbidity of water at the point of collection was measured to be as low as 2 NTU and as high as 10 NTU. Despite having already undergone treatment at the Sundarighat facility, for the purposes of this study, water taken from the faucet will be considered "raw" and "chemically untreated" and, henceforth, referred to as such.

Source water in manual coagulation experiments used water from the tap collected at the Nepal Water Supply Corporation's Central Laboratory or Charles River water drawn from Cambridge, Massachusetts near MIT.

4.5 Data Analysis

Mechanized coagulation studies used $FeCl_3$ from the U.S. manufactured by Eaglebrook, alum from the U.S. manufactured by GAC, and alum taken from the Bansbari and Mahankal Water Treatment Plants in Nepal. Experiments were performed using 1-liter volumes of tap water of treated Sundarighat effluent. Even treated, the effluent from Sundarighat varied dramatically in quality. Therefore, a median and predictable level of quality, gauged in terms of turbidity, could not be assured as a control for the experiments. Some experiments, therefore, were run with initial turbidities around 2 NTU while others were run with turbidity values around 10 NTU. Treatment efficiency was not calculated in experiments where starting turbidity measured less than 3 NTU.

4.6 Coagulation Test Methods

4.6.1 Methods used in this Study

4.6.1.1 Mechanized Coagulation

Mechanized coagulation tests were performed with a Phipps & Bird jar stirrer using a three-phase mixing regime: 0.5 minutes at 100 rpm mixing, 10 minutes at 30 rpm mixing, and 30 minutes of settling with no mixing. Turbidity of the treated samples was measured after 30 minutes of settling.

Settling studies were performed using both 1 and 2 liter volumes of water. After the rapid mix and gentle mix phases, turbidity measurements were taken every 5 minutes for up to two hours.

Long-term settling tests were performed by setting aside a sample of chemically untreated water. Turbidity measurements for this sample were recorded once a day over a period of three days.

4.6.1.2 Manual Coagulation

Manual coagulation tests were run using a hand-stirred regime to test the effectiveness of coagulation for POU treatment. Experiments were performed using bucket-like containers and other household containers that an average Nepali household would have access to. Water was treated with the optimum dose of alum, as determined previously through mechanized jar test experiments. Experiments were performed using two different methods of mixing: jar stirring and jar shaking. Jar stirring applied the use of utensils to mix water whereas jar shaking did not apply utensils to induce mixing but, instead, relied on tilting and shaking the entire lidded jar of raw water to induce mixing. Due to the nature of manual coagulation, stirring speeds are approximate at best. They are, however, roughly equivalent to the mixing speeds imposed in prior mechanized jar test experiments.

4.6.2 Standard Methods

According to the American Water Works Association, the standard method for conducting the mixing regime in a coagulation jar test consists of a three-phase mixing process of rapid mix, gentle mix, and no mix. The rapid mix phase consists of 1 minute of stirring at a speed of 60-80 rpm. The mixing speed is then reduced over the next 30 seconds to 30 rpm, and left to mix at this speed for exactly 15 minutes during the slow mix phase. In the no mix phase, the samples settle for 5, 15, 30, or 60 additional minutes, after which turbidity, pH, and other measurements are taken to quantify changes induced by coagulation and settling.

After coagulant dosing, the turbulent mixing of the rapid mix phase allows sufficient contact between suspended solid particles in water and the injected coagulant. After contact with the coagulant, suspended particles destabilize and become attracted to other particles. At this point, the gentle mixing regime encourages flocculation of particles without breakup, which then settles to the bottom during the final no-mix stage.

The agitation induced by the jar stirrer tests mimics the flocculation process in an actual full-scale water treatment plant. At the point of coagulant dosage, the detention time of the water and chemical mixture should last less than 30 seconds as it flows into flocculation basins (Viessman and Hammer, 1993). Flowing through the basins for a detention time of approximately 30 minutes, water is subjected to either physical or mechanical mixing to induce a phase of gentle mixing (Viessman and Hammer). In water treatment plants with sedimentation facilities, flocculated water proceeds into the sedimentation basins where suspended particles settle to the bottom. In the sedimentation basin, weirs located along the top of the basin collect water free of suspended particles for transport to the next phase of water treatment.

4.6.3 Methods used by a Nepali Lab

Jar tests at the Mahankal laboratory in Nepal are performed by first pre-treating 500 ml of sample water with a 0.1% lime solution. After waiting a few seconds, the water is treated with varying doses of a 1% alum solution. The rapid mix phase lasts 15 seconds under a mixing speed of 110 rpm. The gentle mixing phase lasts 15 minutes under a rate of 60 rpm and the settling period lasts 30 minutes. The doses of alum are tested in increments of 0.5 ml in doses of 5 mg/l. The water is then judged with the eye to determine removal efficiency.

4.6.4 Methods Recommended by Phipps & Bird

Jar test instructions supplied by Phipps & Bird recommend 2-liter sample volumes. They suggest initial rapid mix be conducted at a rate of 300 rpm for a 10- second duration. The flocculation phase consists of a 3-cycle process that lasts for a total of 20 minutes. The first cycle is characterized by a mixing rate of 100 rpm lasting 2 minutes before a reduction to 60 rpm lasting 3 more minutes. Finally, mixing speeds are reduced to 20 rpm for the last 15 minutes. When testing for optimum flocculation times, there is no practical reason for the phase to exceed 80 minutes. The settling phase begins after a 30-second lag time after the mixing of paddles is turned off and simulates the transport time from flocculation basin to sedimentation basin (Wagner, 1993).

4.6.5 Comparison of all Described Methods

Of the mixing regimes presented, the regime followed in this study and by the Nepali laboratory at the Mahankal Water Treatment Plant more closely resemble the standard methods of the American Water Works Association. The differences between the laboratory procedures recommended by Phipps & Bird and the procedures actually followed in studies in this report vary dramatically in the flocculation phase. Phipps & Bird suggests a multiphase flocculation process that is, for the purpose of adaptation into POU treatment, extremely complicated and, thus, inapplicable. For manual coagulation techniques to be successful, the process must be easy to implement. A single-phase mixing regime should be much more accessible to rural village women who are not accustomed to pretreatment water processes. For these reasons, laboratory procedures were conducted using a simplified one-phase flocculation regime that was similar to the standard methods presented by the American Water Works Association.

5.0 Experimental Results

5.1 Effect on Turbidity

Turbidity was analyzed with respect to final turbidity results (See Figure 5-1) as well as turbidity removals using two different starting samples, "raw" and "zero", as control. "Raw" samples refer to chemically untreated water that has not undergone any period of stirring or settling. "Zero" samples refer to chemically untreated water which has gone through the same stirring and settling regime as chemically dosed water. The results of turbidity removal analyses with respect to zero and raw samples are shown in Figures 5-2 and 5-3, respectively, and will be discussed in detail. Removal efficiency based on turbidity of raw water can better determine the effectiveness of water treatment process as a whole, including both the coagulation and settling component of treatment. On the other hand, zero water as control better isolates the dosage parameter because of shared stirring and settling history with experimental samples. A combination of both analyses provides a more complete picture of optimum dosage.

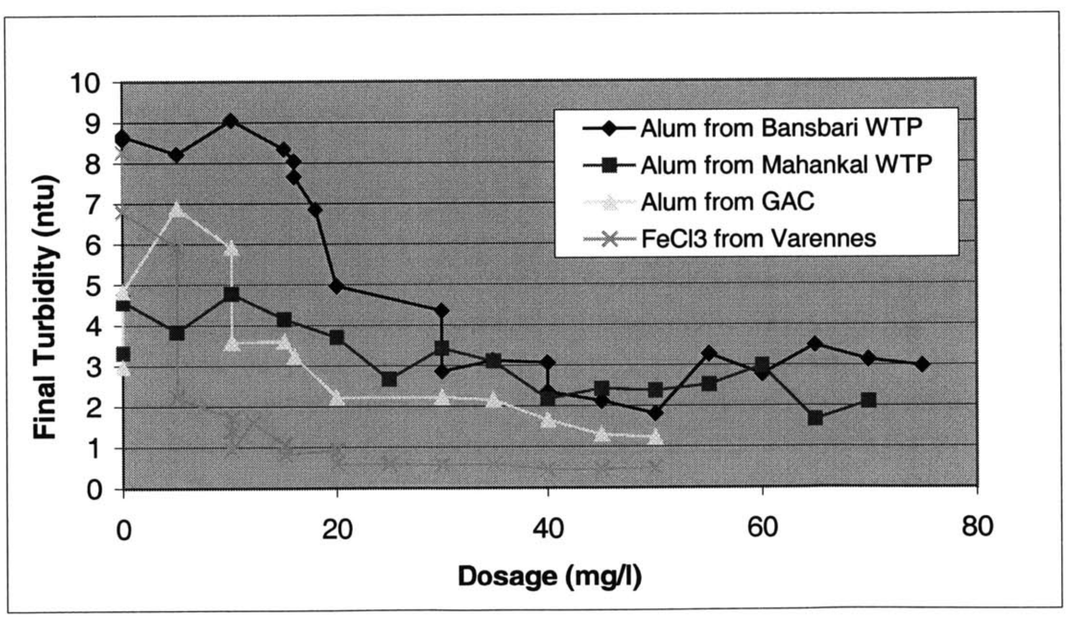

FIGURE 5-1: FINAL TURBIDITY VS. DOSAGE

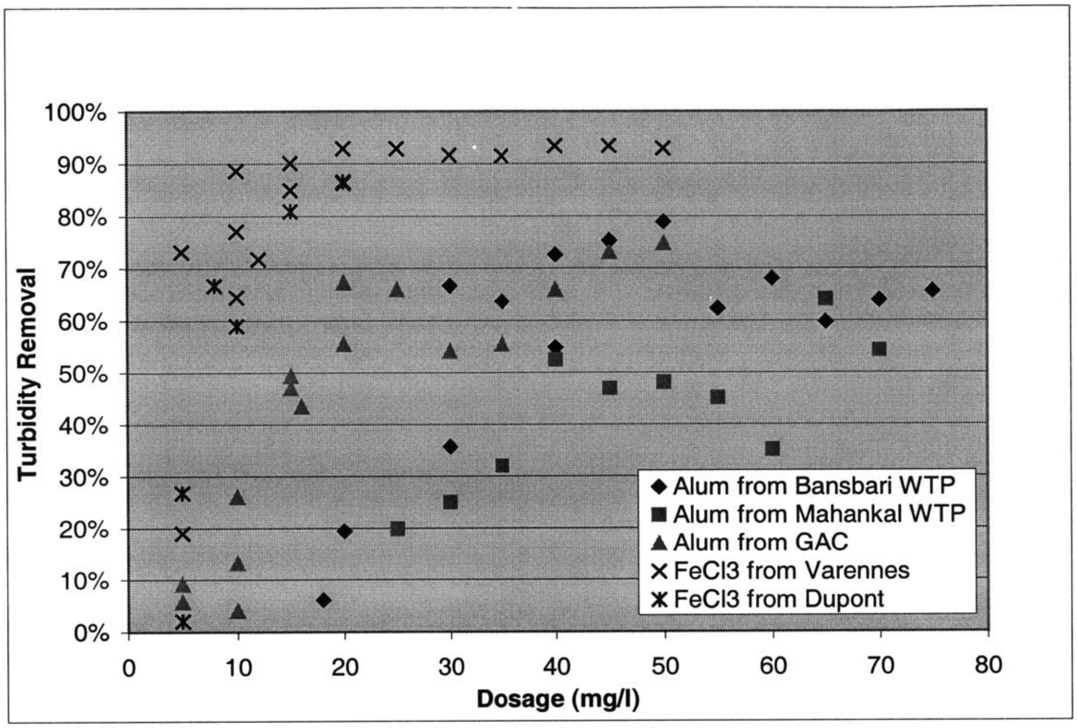

FIGURE 5-2: TURBIDITY REMOVAL EFFICIENCIES BASED ON "ZERO" SAMPLES AS CONTROL

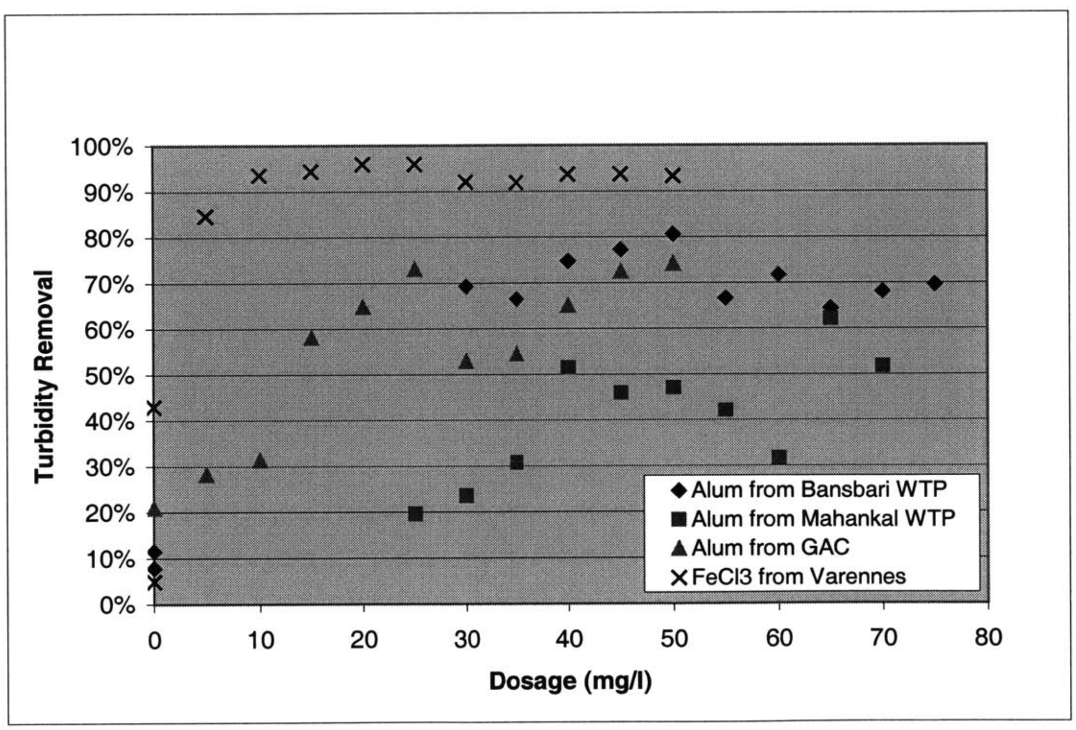

FIGURE 5-3: TURBIDITY REMOVAL EFFICIENCIES BASED ON "RAW" SAMPLES AS CONTROL

5.1.1 $FeCl_3$ Coagulant

Compared to all coagulants studied, $FeCl_3$ requires the least amount of dosage to achieve the greatest amount of turbidity removal. Even at levels of 10 mg/l, turbidity removals between 64% and 89% were achieved. In analysis using the zero samples as control, $FeCl_3$ doses of 20 mg/l were found to achieve optimum turbidity removals of 93%. Doses greater than 20 mg/l did not necessarily improve turbidity removal. Removal efficiencies beyond this point hover around the low ninetieth percentile despite increases of dosage up to 50 mg/l. At and beyond the optimum dose of 20 mg/l, final turbidity was reduced to levels of 0.59 NTU. Even at half of this optimum dose, the final reading of turbidity remains extremely low with values between 0.94 NTU to 1.72 NTU. Analysis using raw water as control shows turbidity removal efficiencies in $FeCl_3$ tapering off after 10 mg/l. Reducing final turbidity levels to the World Health Organization's acceptable limit of 5 NTU for drinking water requires a dose of only 10 mg/l. Optimum doses, which can reduce turbidity to levels below WHO limits, were determined from zero-sample and raw-sample analyses to be 20 mg/l and 10 mg/l, respectively. The more conservative dose 20 mg/l will be taken as dosage for optimum turbidity removal.

5.1.2 U.S.-Manufactured Alum Coagulant

United States quality alum, manufactured by GAC, yielded turbidity removal results second only to $FeCl_3$. Analysis using both zero-samples and raw-samples as control show that optimum turbidity removal is achieved at a dose of 20 mg/l. The effectiveness of GAC alum treatment with respect to turbidity removal efficiency tapers off after 20 mg/l. Around these values, a 55%-67% reduction in turbidity is found. Even when dosage is increased to values as high as 50 mg/l, maximum turbidity removal only slightly increases to 75%. Turbidity removal in experimental runs with doses greater than 20 mg/l hovers around 50% and suggests an upper bound limit of removal efficiency. At low dosages, turbidity removal is poor, especially when compared to $FeCl_3$, which achieved excellent turbidity removal even at doses as low as 10 mg/l. At this dosage, GAC alum achieves only a 25% decrease in turbidity. Analysis with raw samples shows removal efficiencies ranging between 53%-74% for dosages beyond 15 mg/l up to 50 mg/l. Final turbidity values dramatically improve in doses greater than 20 mg/l to stabilize around values between 1.22-2.22 NTU.

5.1.3 Nepal Alum Coagulant

Of the two types of Nepali alum tested, Bansbari alum yielded the best results. Analyses using zero-samples as control show effective removal results for doses of Bansbari alum greater than or equal to 30 mg/l. Doses less than this value were ineffective in removing turbidity and, in fact, only added to existing turbidity. The two runs conducted at 30 mg/l showed dramatically disparaging results, with separate trials exhibiting removal efficiencies of 67% and 36%. At doses between 35 mg/l and 75 mg/l, removal efficiencies consistently hovered in the range of 55%-79%. Beyond 35 mg/l, larger doses did not necessarily ensure better removal efficiencies. However, this may largely have been a result of different starting turbidities since the source of water used in experiments was of unpredictable quality. In analyses with raw-samples, dosages between 30 mg/l and 75 mg/l yielded removal efficiencies that fluctuated between 64% and 81% removal. Further analysis of the raw data shows that maximum turbidity removal occurred at the maximum dose for each run. That is, in each series run, the sample treated with the greatest amount of coagulant yielded the best turbidity removal. Overall however, the general trend shows a tapering off of removal efficiency in all experiments involving dosages greater than 35 mg/l. The lowest final turbidity values were achieved in applications of alum dose in the range of 40-50 mg/l. Samples treated with doses outside this range result in higher final turbidity values. This suggests that water incurs a maximum success level with Nepal alum.

Mahankal alum yields turbidity removal efficiencies around 50% at doses greater than or equal to 40 mg/l in analyses using zero-samples as control. More specifically, doses between 40 mg/l and 55 mg/l achieve removal efficiencies ranging from 45%-52%. Doses greater than 55 mg/l yield results that fluctuate more dramatically and unpredictably. These fluctuations, however, are most likely due to variations in water samples in each run and may not be indicative of a larger trend. The overall trend suggests that dosages greater than or equal to 40 mg/l achieve the best removal. Analysis using raw-sample data, as shown in Figure 5-2, leads to the same conclusions. In fact, as dosage increases from 40 mg/l to 60 mg/l, the efficiency of removal actually decreases. Optimum final turbidity values are found in the coagulant dose range of 40-55 mg/l and yield turbidities between 2.17 NTU to 2.52 NTU.

Results for the two types of Bansbari and Mahankal alum were then analyzed to determine a conservative coagulant dose that would be applicable to many variations of Nepal alum. Although zero-sample and raw-sample analyses of Bansbari alum suggest optimum turbidity removal occurs at 30 mg/l, the same analysis using Mahankal alum suggests doses greater than or equal to 40 mg/l yield optimum turbidity reduction. The lowest final turbidity values in samples with Bansbari and Mahankal alum were achieved at doses between 40-50 mg/l and 40-55 mg/l, respectively. Conservative calculations conclude that optimum turbidity removal results should be achieved at a dose of 40 mg/l for any Nepal alum variation.

5.2 Effect on pH

The pH value decreases as the amount of metal salt coagulant in a system increases. The acidic increase in a system is, of course, a function of the coagulant type. Comparable amounts of dosage show greater pH drops in $FeCl_3$ treated waters than in alum treated waters. This is especially true in the high range of dosages greater than or equal to 35 mg/l. As shown in Figure 5-4, a dosage of 50 mg/l of $FeCl_3$ induces a 1.0 drop in pH. However, hierarchy of degree of change in pH only applies at higher dose levels. The inconsistency of this data is best illustrated by experiments using low doses. At low doses, the results are much more scattered and inconclusive. At higher doses, the influence of coagulants on pH is easier to note. However, due to inconsistencies in the data from low doses, a quantitative conclusion relating coagulant type, dose, and effect on pH drop cannot be drawn.

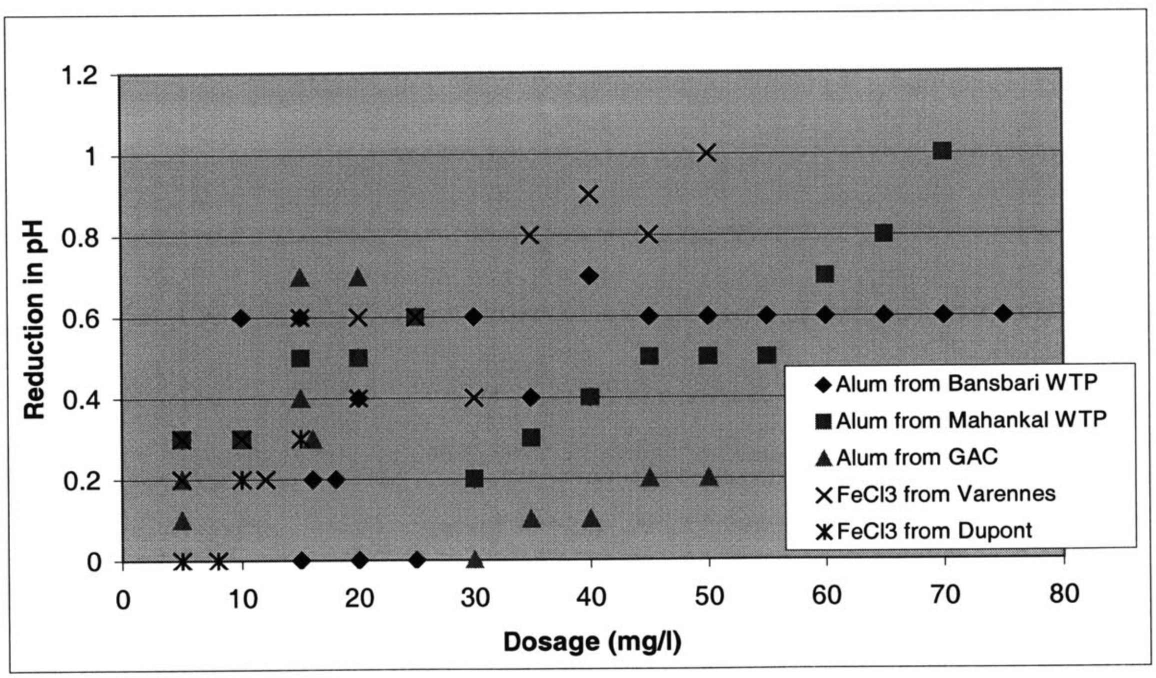

FIGURE 5-4: REDUCTION IN PH VS. DOSAGE

Analyses of final pH readings show more predictable and consistent results, as shown in Figure 5-5. After treatment using comparable doses, $FeCl_3$ treated samples show the lowest final pH levels that are significantly lower than that observed in alum treated samples. The next lowest pH levels observed are found in samples treated with Bansbari alum, GAC alum, and Mahankal alum, in that order. The stabilization of final pH values as seen in experiments using Bansbari alum, despite increases of coagulant quantity, is not scientifically logical. Therefore, the main conclusion that can be drawn from this data is a qualitative rather than quantitative comparison of the effect of different coagulant additions on pH.

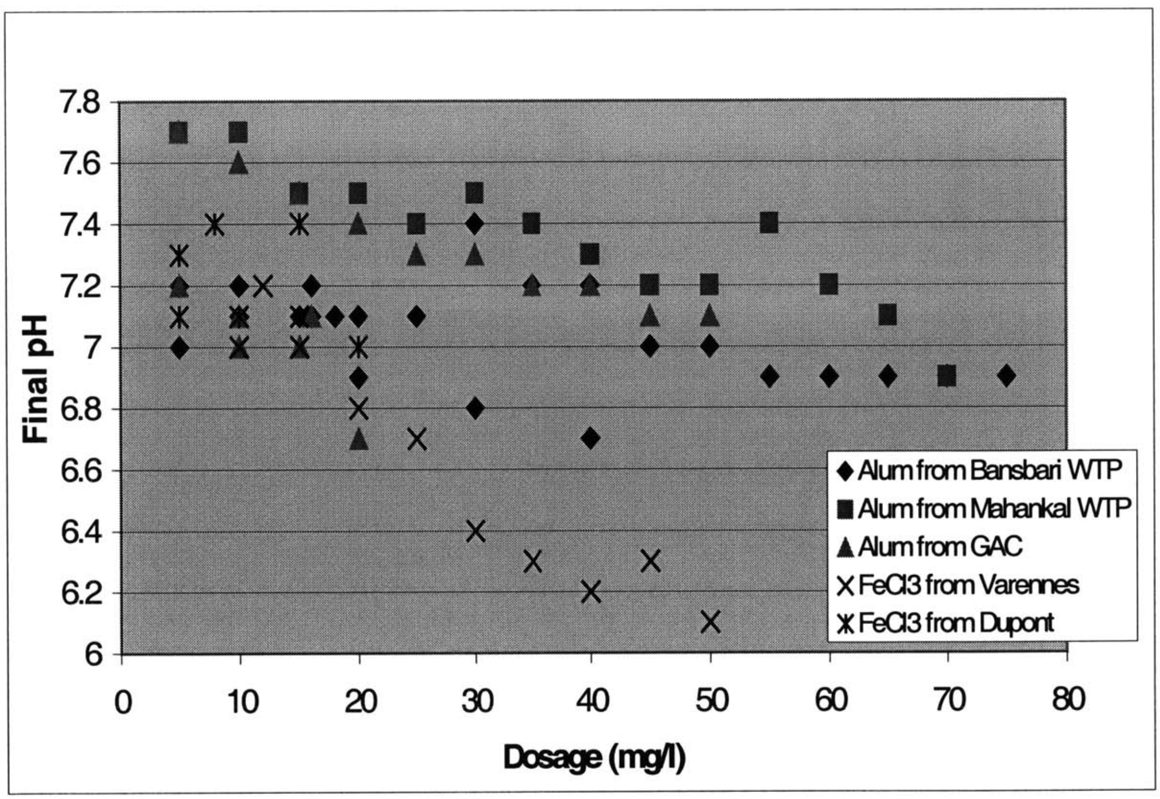

FIGURE 5-5: FINAL PH VS. DOSAGE

5.3 Results of POU Coagulation experiments

Various techniques of mixing were employed to test the applicability of manual coagulation. Initially, experiments were run in which mixing was performed by jar shaking. Later tests, which used jar stirring methods that applied utensils to mix the dosed water, were found to achieve much better results.

Jar shaking as a stirring method yielded poor formation of floc particles and, consequently, poor turbidity reduction. Poor performance can most likely be attributed to inadequate inter-particle contact due to improper mixing speeds and method of mixing. Jar shaking produces irregular and uncontrolled mixing that inaccurately mimics mixing speeds of mechanized jar tests, resulting in poor floc formation or floc breakup. The geometry of the round container also contributes to inadequate particle contact because it lacks the turbulence-inducing corners of laboratory beakers. The difference between fluid flow mixing in square containers such as laboratory beakers and round containers are shown in Figure 5-6 below.

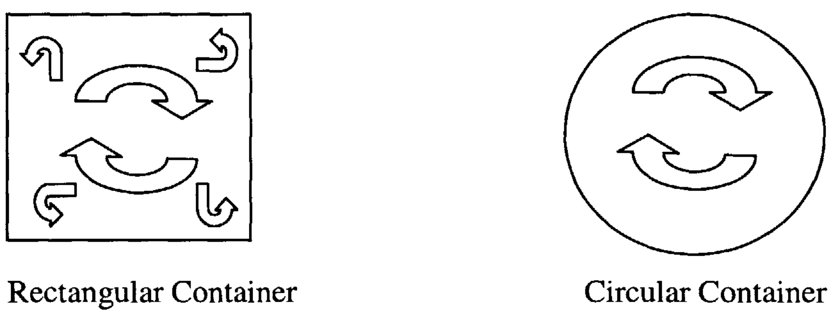

FIGURE 5-6: THE CORNERS OF RECTANGULAR SHAPED CONTAINERS CONTRIBUTE TO BETTER MIXING THAN ROUND CONTAINERS.

Jar stirring more closely simulates the mixing dynamics of mechanized jar test experiments because the use of a utensil allows better control over mixing speeds and more turbulent mixing. In order to make hand-mixing more similar to the paddle-mixing of mechanical coagulation regimes, a spatula was used. The 100 rpm rapid mix phase was emulated by stirring at approximately 1.5 rotations per second. The 30 rpm slow mix phase was emulated by stirring rate at a rate of 0.5 rotations per second. In order to achieve better inter-particle contact, the direction of stirring was gently reversed during mixing so that the water was not simply being swirled around as one unit volume inside the round container. Instead, the reversal of the stirring direction adds controlled turbulence to the system and offsets some of the drawbacks of round containers.

In jar-stirring manual coagulation experiments, floc particles measured approximately 2 mm after 15 minutes of settling. After 30 minutes, floc particles had reached a size of 4 mm and a layer of settled floc particles had formed on the bottom of the container. Moreover, noticeable color had been removed from the raw water so that the initial yellow hue of the Charles River water looked more diluted. Turbidity and color reductions were qualitatively recorded because the turbidimeter used in previous experiments was in-use on other field projects and, consequently, unavailable at the time these experiments were performed. After a full hour of settling, turbidity of the water was improved as more floc particles settled out of the system. This experiment is documented in the series of photographs in Figure 5-7 below.

FIGURE 5-7: MANUAL COAGULATION AND SETTLING EXPERIMENT. (A) RAW WATER; (B) AT START OF SETTLING TIME; (C) AFTER 30 MINUTES OF SETTLING.

6.0 Feasibility of Implementation of POU Treatment

6.1 Education

Because street alum used for purposes other than as an antiseptic or shaving cream is rare, a program to educate villagers on the water treatment uses of alum needs to be implemented. A visit to Nepal revealed a possible means to spread this message. At a UNICEF sponsored water treatment seminar held in a rural village, a group of respected upper-caste Nepali women attended the seminar with the intention of spreading the word on effective affordable treatment methods. A similar system could be employed to disseminate POU coagulation instructions. Local Nepalis would be the best messengers of this information because they would be able to better tackle cultural differences and relate to rural villagers when explaining instructions.

6.2 Equipment

In order to make manual coagulation accessible to rural Nepali people, the instruments used must be both easily accessible and widely available. The only supplies required are containers, mixing utensils, and volumetric measurements. Containers can be gagros, buckets or other types of container capable of holding large volumes of water for household-scale volumes of water treatment. From informal field interviews with Nepali people conducted in January 2000, gagros and buckets were found to be commonplace in households. However, buckets are recommended over gagros because the surface opening of a bucket is larger than that of a gagro, making it easier to mix water and gauge floc formation. In addition, buckets, usually made of plastic, cost less than gagros. Mixing utensils can be any type of paddle type utensil such as a spoon, spatula, fork, etc.

In order to translate metric measurement into a quantity accessible to rural Nepali people, volumetric instruments were adapted from available materials because rural Nepalis generally do not have access to volumetric measurements such as measuring cups or utensils of standard volume. Because marked volumes on utensils and containers are uncommon in Nepali households and even spoons are made with varying volumetric capacities, the most appropriate method of measurement found was the widely available plastic bottles of drinking water that come in measured volumes. These plastic drinking water bottles can commonly be found for sale in any store. The cap of the bottle can be used as a measuring device and the bottle itself can be used to hold stock coagulant solution. The cap of the bottle, depending on the meniscus, can contain anywhere between 7.5-10 ml of liquid. When leveled to the top, the cap can hold approximately 5 g of alum. The plastic bottle used to create coagulant solution should be small and of 500 ml volume.

6.3 Distribution

Distribution of alum is much simpler than distribution of Moringa Oleifera seeds used in Africa and parts of Asia because most households already have alum on hand or are easily able to obtain it, as learned through interviews with Nepalis. However, the successful distribution of Moringa Oleifera seeds to non-indigenous cultures serves as testimony that even under a worst case scenario, dissemination of coagulant is possible. In mass quantities, as used by water treatment plants, alum is imported directly from India. In smaller quantities, as would be used by average Nepali households, alum can easily be bought on the streets in cities and towns. Even though the availability of alum in rural areas may be less accessible than in urban areas, local transportation between rural areas and nearby towns should ease this difficulty.

Suggestions from the Jahn article to pursue the coagulation phases while chanting set phrases to ensure standardized mixing speeds may be helpful but unnecessary. Manual coagulation experiments conducted where mixing speeds were gauged in terms of rotations per second provide adequate standardization of procedures.

6.4 Cost

In order to be a feasible option, the coagulation process in POU treatment must be affordable for rural Nepalis. A cost breakdown of all supplies needed for coagulation is listed below alongside cost breakdown for filters (Sagara, 2000). Because the average annual per capita income in Nepal is US$ 210,[4] the total cost of supplies needed to implement POU treatment is a strong factor in determining its feasibility. The per capita income is averaged over both urban and rural populations, with 47% of the rural population and only 18% of the urban population falling below poverty.[4] As a result, a group of urbanites make up the bulk of the income accounted for in this income per capita analysis. The income of the average rural Nepali is even lower.

TABLE 6-1: COST OF MANUAL COAGULATION SUPPLIES[5]

Item	Cost (US$)
Street alum	$0.50 for 100 g
Mortar and pestle	$5.00
Plastic water bottle	$0.25
Total cost:	$5.75

[4] United Nations Development Programme (UNDP), Nepal Human Development Report, 1998
[5] Quoted market price in January 2000. Prices may vary between stores and towns.

TABLE 6-2: COST OF VARIOUS TYPES OF FILTER SYSTEMS[6]

Item	Cost (US$)
Nepali-made Filter- ceramic container with 2 candle filters	$3.00
Nepali-made Filter- bucket container with 2 candle filters	$3.50
Indian-made Filter- stainless steel container with 2 candle filters	$8.60-$23.20
Industry for the Poor Brand Purifier	$15.00
Lowest cost of filter system:	$ 3.00

The cost of all supplies needed for POU coagulation is $5.75. The cost of the most inexpensive filter system available in Nepal is $3.00. Although the cost of POU coagulation exceeds that of the filters, a closer look at the cost analysis will show that coagulation costs cost approximately equal to if not less than that of the filter costs.

The greatest contributor to the price of POU coagulation is the mortar and pestle at a price of US$ 5.00. However, this is the price as paid for at a retail store. A mortar and pestle bought from a vendor at any local street market should cost significantly less than that in a retail store. Due to limitations in time, such a search was not possible. In addition, because prices quoted to non-Nepali people tend to be inflated, the actual price may be lower than indicated in this cost analysis. Most importantly, because most Nepali families already own a mortar and pestle for cooking or medicinal purposes, the inclusion of it in this cost analysis is redundant and unnecessary. Excluding the mortar and pestle, the total cost of POU coagulation supplies is only US$ 0.75.

The distribution system of the inexpensive Nepali filter system is currently limited. From a visit to Nepal in January 2000, the most widespread filters available in Nepal appeared to be the Indian-made filters. At a cost of at least $8.60, few rural Nepalis can afford them. The alum,

[6] Sagara, 2000

often used as an aftershave, is better distributed throughout Nepal and is both more affordable as well as more accessible.

7.0 Conclusions

7.1 Applications in POU Treatment

Although mechanized coagulation is far more precise and effective than manual coagulation, manual coagulation is the only feasible option for applications in POU treatment. Experiments with manual coagulation using jar stirring have yielded promising results with substantial turbidity and color removal from the settling of floc particles. Manual coagulation using the jar shaking as the stirring method was ineffective in reducing color and turbidity.

To properly treat water using POU treatment, the appropriate dose needs to be pre-determined and the dosing regime adjusted accordingly. This study has found an appropriate dose of 40 mg/l of Nepal alum for water collected in the dry season. Consequently, raw water turbidity is much lower than it would be if sampled in the rainy season. Dosage should be adjusted accordingly using 40 mg/l for dry season raw water as a starting point until more studies can be performed.

The step by step process of POU coagulant treatment is specified below:

Directions for making 2% coagulant solution:

1. Grind solid alum into a powder using mortar and pestle.
2. Pour two level capfuls of powdered alum to into the 500 ml plastic drinking water bottle of the type available in Nepal.
3. Fill the 500 ml bottle to the top with clean water.
4. Shake well before use and allow the solid particles to dissolve completely in solution.

Directions for 40 mg/l dose using 2% coagulant solution:

1. For every 2 liters of water, add one capful of solution.
2. Stir rapidly for 30 seconds to 1 minute using spoon or other paddle type device. Rate of mixing should be 100 rpm, or approximately 1.5 rotations per second.
3. Stir slowly for 10 minutes at 30 rpm, or ½ rotation per second. In order to ensure adequate mixing without breaking up flocculated particles, be sure to gently change direction of stirring for better results.
4. Allow water to settle for a minimum of 30 minutes.
5. For consumption, use a ladle to collect water from the top or pour water out, being careful not to disturb settled floc particles at the bottom.

One capful of 2% solution per every 2 liters of water provides a dose of 40 mg/l. Larger volumes of water will, of course, require more solution. The calculations for this dosing regime can be found in Appendix A.

Although more complicated than using manufactured filters as the initial particle removal step in an overall POU treatment strategy, POU coagulation as a pretreatment for drinking water is definitely a feasible option. It has shown to be an economically viable means of effectively removing turbidity and color from raw water. Compared to filters, costs of the small plastic drinking water bottle and alum are minimal. However, POU coagulation does not completely eliminate color or turbidity in water over the time frame studied and, thus, reduces but does not eliminate the need for a filter. The use of high quality alum, not known to be widely available in Nepal, will of course increase turbidity removal. Nevertheless, POU treatment can be especially useful during the rainy months, when turbidity of water increases by almost tenfold, to increase the effectiveness of filters.

6.2 Applications in POD Treatment

Although ferric chloride has shown to be the most efficient coagulant tested, it is unavailable in Nepal. Interviews with water treatment plant managers and operators have revealed that alum is the only type of coagulant available in Nepal. There are no sources of alum in Nepal, and all quantities must be imported from nearby India. Locally available alum, unlike the laboratory quality solution found in the United States that was used in this study, is available only in solid form of quality which varies from one shipment to the next. Although this alum is of questionable and unpredictable quality, cost and distribution restrictions make it the only feasible option. The best coagulant dosage of Nepal alum has been found to be 40 mg/l. At doses higher than this amount, the level of turbidity removal tapers off even as greater doses are added. Moreover, large quantities of alum lead to large reductions in pH which require larger additions of lime or soda ash for pH adjustment. Data analysis shows that the 40 mg/l dose represents the optimum compromise between pH reduction and turbidity removal.

This dose should be implemented at the Mahankal and Bansbari Water Treatment Plants for greater treatment efficiency. As the in-solution dosing facilities at Balaju come online in late 2000, this recommended dosage should also be applied at that treatment plant. Because the Sundarighat Treatment Plant does not currently possess coagulation facilities capable of precise dosing, no recommendations for that facility will be made at this time.

It is important to note, however, that these conclusions were made based on studies using raw water with turbidity in the range of 4-10 ntu. During the rainy season when turbidity increases to as much as 1500 ntu, the recommended 40 mg/l dose will not be sufficient. Further studies should be done using raw water collected during the rainy season to determine an appropriate alum dosage.

Appendix

Appendix A: Calculations for dosing regime used to make 40 mg/l.

Let n = number of capfuls of solution

$$\frac{\text{concentration of solution} * n * \text{volume of solution}}{\text{volume of water to be treated}} = \text{optimum dose}$$

$$n = \frac{\text{optimum dose} * \text{volume of water to be treated}}{\text{concentration of solution} * \text{volume of solution}}$$

$$n = \frac{40 \text{ mg/l} * 2 \text{ l}}{10 \text{ g/500 ml} * 7.5 \text{ ml}}$$

n = number of capfuls of solution = 1.06 ~ 1 capful

Appendix B: Coagulation Jar Test Data Sheets

Coagulation Jar Test Data

Date: 1/16/00 **Time:** 3
Sampling Location: Bagmati River
Run #: 1

T (deg C): 14
pH: 7

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
min rpm
min rpm

	Chemicals Added					Analysis Performed		
Sample	Dupont $FeCl_3$ (mg/l)	Varennes Alum (mg/l)	GAC Alum (mg/l)			pH	turbidity	Visual Observations
Raw								
Jar 1							72.5	Floc size (mm):
Jar 2	25						20.2	
Jar 3		25					53.2	
Jar 4			25				15.7	
Jar 5								
Jar 6								
Duplic.								
Duplic.								

Purpose: Test out dosages extremely high starting turbidity conditions

Notes:

Coagulation Jar Test Data

Date: 1/16/00 **Time:** 5:00
Sampling Location: Central Lab Tap
Run #: 2

T (deg C): 15
pH: 7.2

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
min rpm
min rpm

	Chemicals Added					Analysis Performed		
Sample	Dupont $FeCl_3$ (mg/l)	GAC Alum (mg/l)				pH	turbidity	Visual Observations
Raw								
Jar 1						72.5		Floc size (mm):
Jar 2	50					14.9		
Jar 3		50				26.7		
Jar 4								
Jar 5								
Jar 6								
Duplic.								
Duplic.								

Purpose: Test out dosages extremely high starting turbidity conditions

Notes: FeCl3 water is clogged at outlet, water slowly drips out.

Coagulation Jar Test Data

Date: 1/17/00 **Time:** 11:50
Sampling Location: Central Lab Tap
Run #: 3

T (deg C): 12
pH: 7.1

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
min rpm
min rpm

	Chemicals Added					Analysis Performed		
Sample	Dupont $FeCl_3$ (mg/l)	Varennes Alum (mg/l)	GAC Alum (mg/l)	Bansbari alum (mg/l)		pH	turbidity	**Visual Observations**
Raw								Floc size (mm): 0
Jar 1	0	0	0	0		6.9	4.84	0.5
Jar 2	5					7.1	3.54	0.8
Jar 3		10				7.1	1.75	0.5 numerous, better floc than alum
Jar 4			10			7.1	3.58	little to no floc
Jar 5				10		7.2	5.01	
Jar 6								
Duplic.								
Duplic.								

Purpose: compare locally available alum w/ US available coagulants

Notes: locally available alum (nepal alum) doesn't seem as effective

Coagulation Jar Test Data

Date: 1/17/00 **Time:** 1:40
Sampling Location: Central Lab Tap
Run #: 4

T (deg C): 14
pH:

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
min rpm
min rpm

	Chemicals Added					Analysis Performed		
Sample	Bansbari solid alum (mg/l)	Bansbari solid alum (mg/l)	Bansbari solid alum (mg/l)	Bansbari solid alum (mg/l)		pH	turbidity	**Visual Observations**
Raw								
Jar 1						6.9	53	Floc size (mm): 0
Jar 2	1000					4.1	20.4	0.6
Jar 3		2000				3.6	40.1	0.9
Jar 4			3000			3.9	46.6	1.4
Jar 5				5000		3.6	77.7	2.5 floc float to surface
Jar 6								
Duplic.								
Duplic.								

Purpose: Test out dosages extremely high starting turbidity conditions

Notes: doses much too high. Should add in solution next time instead of as solid.

Coagulation Jar Test Data

Date: 1/18/00 **Time:** 11:06
Sampling Location: Central Lab Tap
Run #: 5

T (deg C): 13
pH:

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
min rpm
min rpm

Sample	Chemicals Added					Analysis Performed		Visual Observations
	Dupont $FeCl_3$ (mg/l)	Varennes Alum (mg/l)	GAC Alum (mg/l)	Bansbari alum (mg/l)	Bansbari (solid form) (mg/l)	pH	turbidity	
Raw								
Jar 1	0	0	0	0	0	7.4	5.7	Floc size (mm): 0
Jar 2	8					7.4	1.9	0.65
Jar 3		12				7.2	1.61	0.85
Jar 4			16			7.1	3.22	0.6
Jar 5				16		7.2	7.66	0
Jar 6					800	4.2	32.4	very turbid, no floc, just cloudy
Duplic.								
Duplic.								

Purpose: find optimum dosage of coagulant for tap water

Notes: solid alum not fully dissolved in water, too much solid alum. Next time, need to use in solution.
nepal alum not performing as well as GAC alum.

Coagulation Jar Test Data

Date: 1/20/00 **Time:** 11:50
Sampling Location: Central Lab Tap
Run #: 6

T (deg C): 12
pH: 7.5

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
min rpm
min rpm

Sample	Chemicals Added					Analysis Performed		Visual Observations
	Dupont $FeCl_3$ (mg/l)	Varennes Alum (mg/l)	GAC Alum (mg/l)	Bansbari alum (mg/l)	Bansbari alum (mg/l)	pH	turbidity	
Raw								
Jar 1	0	0	0	0	0	7.7	7.09	Floc size (mm): 0
Jar 2	15					7.4	1.36	0.85
Jar 3		15				7.1	1.07	0.9
Jar 4			15			7	3.59	0.5
Jar 5				15		7.1	8.34	0.25
Jar 6					10	7.1	9.05	0.1
Duplic.								
Duplic.								

Purpose: find optimum dosage of coagulant for tap water

Notes:

Coagulation Jar Test Data

Date: 1/20/00 **Time:** 12:55
Sampling Location: Central Lab Tap
Run #: 7

T (deg C): 12
pH: 7.5

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
min rpm
min rpm

Sample	Chemicals Added					Analysis Performed		Visual Observations
	Dupont $FeCl_3$ (mg/l)	Varennes Alum (mg/l)	GAC Alum (mg/l)	Bansbari alum (mg/l)	Bansbari alum (mg/l)	pH	turbidity	
Raw								
Jar 1	0	0	0	0	0	7.3	6.16	Floc size (mm): 0
Jar 2	10					7.1	2.53	0.65
Jar 3		10				7	1.41	0.8
Jar 4			10			7	5.91	0.3
Jar 5				20		6.9	4.96	0.6
Jar 6					5	7	8.22	0
Duplic.								
Duplic.								

Purpose: find optimum dosage of coagulant for tap water

Notes:

Coagulation Jar Test Data

Date: 1/20/00 **Time:** 2:00
Sampling Location: Central Lab Tap
Run #: 8

T (deg C): 14
pH: 7.2

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
min rpm
min rpm

Sample	Chemicals Added					Analysis Performed		Visual Observations
	Dupont $FeCl_3$ (mg/l)	Varennes Alum (mg/l)	GAC Alum (mg/l)	Bansbari alum (mg/l)	Bansbari alum (mg/l)	pH	turbidity	
Raw								
Jar 1	0	0	0	0	0	7.4	6.77	Floc size (mm): 0
Jar 2	20					7	0.91	0.6
Jar 3		20				6.8	0.93	0.7
Jar 4			20			6.7	2.22	0.3
Jar 5				30		6.8	4.35	0.35
Jar 6					40	6.7	3.06	0.35
Duplic.								
Duplic.								

Purpose: find optimum dosage of coagulant for tap water

Notes: Varennes consistently flocculates better
perhaps alum needs longer time to settle

Coagulation Jar Test Data

Date: 1/20/00 **Time:** 3:00 PM
Sampling Location: Central Lab Tap
Run #: 9

T (deg C): 16
pH: 7.3

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
min rpm
min rpm

Sample	Chemicals Added					Analysis Performed		Visual Observations
	Dupont $FeCl_3$ (mg/l)	Varennes $FeCl_3$ (mg/l)	GAC Alum (mg/l)	Bansbari Nepal Alum (mg/l)	Bansbari Nepal Alum (mg/l)	pH	turbidity	
Raw								
Jar 1	0	0	0	0	0	7.3	6.64	Floc size (mm): 0
Jar 2	5					7.3	7.15	0.1
Jar 3		5				7.1	5.91	0.3
Jar 4			5			7.2	6.88	0
Jar 5				16		7.1	8.04	0.2
Jar 6					18	7.1	6.85	0.3
Duplic.								
Duplic.								

Purpose:

Notes:

Coagulation Jar Test Data

Date: 1/23/00 **Time:** 10:45
Sampling Location: Central Lab Tap
Run #: 10

T (deg C): 13
pH: 7.7

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
min rpm
min rpm

Sample	Chemicals Added					Analysis Performed		Visual Observations
	Varennes $FeCl_3$ (mg/l)	Alum (mg/l)				pH	turbidity	
Raw						7.7	14.5	Floc size (mm): 0
Jar 1	0					7.4	8.27	0
Jar 2	5					7.1	2.22	0.3
Jar 3	10					7.1	0.94	0.65
Jar 4	15					7	0.82	0.7
Jar 5	20					6.8	0.59	0.75
Jar 6	25					6.7	0.59	0.8
Duplic.								
Duplic.								

Purpose: standardized dosage of FeCl3

Notes:

Coagulation Jar Test Data

Date: 1/23/00 **Time:** 11:53
Sampling Location: Central Lab Tap
Run #: 11

T (deg C): 13
pH: 7.15

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
min rpm
min rpm

	Chemicals Added					Analysis Performed		
Sample	Varennes $FeCl_3$ (mg/l)	Alum (mg/l)				pH	turbidity	Visual Observations
Raw						7.15	7.15	Floc size (mm): 0
Jar 1	0					7.1	6.8	0
Jar 2	30					6.4	0.57	1.5
Jar 3	35					6.3	0.58	1.5
Jar 4	40					6.2	0.45	1.5
Jar 5	45					6.3	0.45	1.6
Jar 6	50					6.1	0.48	1.7
Duplic.								
Duplic.								

Purpose: find optimum dosage of coagulant for tap water

Notes:

Coagulation Jar Test Data

Date: 1/23/00 **Time:** 1:08
Sampling Location: Central Lab Tap
Run #: 12

T (deg C): 13
pH: 6.8

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
min rpm
min rpm

	Chemicals Added					Analysis Performed		
Sample	Varennes $FeCl_3$ (mg/l)	Bansbari Alum (mg/l)				pH	turbidity	Visual Observations
Raw						6.8	1.52	Floc size (mm): 0
Jar 1		0				7.1	2.17	0
Jar 2		5				7.2	2.92	0
Jar 3		10				7.2	4.02	0.1
Jar 4		15				7.1	4.04	0.2
Jar 5		20				7.1	4.23	0.3
Jar 6		25				7.1	3.13	0.4
Duplic.								
Duplic.								

Purpose: standardized dosage of Bansbari Alum

Notes:

Coagulation Jar Test Data

Date: 1/23/00 **Time:** 2:52
Sampling Location: Central Lab Tap
Run #: 13

T (deg C): 15
pH: 7.6

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
min rpm
min rpm

Sample	Chemicals Added					Analysis Performed		Visual Observations
	Varennes $FeCl_3$ (mg/l)	Bansbari Alum (mg/l)				pH	turbidity	
Raw						7.6	9.31	Floc size (mm): 0
Jar 1		0				7.6	8.58	0
Jar 2		30				7.4	2.86	0.6
Jar 3		35				7.2	3.12	0.6
Jar 4		40				7.2	2.35	0.6
Jar 5		45				7	2.12	0.6
Jar 6		50				7	1.81	0.6
Duplic.								
Duplic.								

Purpose: standardized dosage of Bansbari Alum

Notes:

Coagulation Jar Test Data

Date: 1/25/00 **Time:** 11:00
Sampling Location: Central Lab Tap
Run #: 15

T (deg C): 14
pH: 7.3

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
min rpm
min rpm

Sample	Chemicals Added					Analysis Performed		Visual Observations
	Varennes $FeCl_3$ (mg/l)	GAC Alum (mg/l)				pH	turbidity	
Raw						7.3	4.71	Floc size (mm): 0
Jar 1		0				7.3	4.83	0
Jar 2		30				7.3	2.22	0.5
Jar 3		35				7.2	2.15	0.5
Jar 4		40				7.2	1.65	0.5
Jar 5		45				7.1	1.3	0.5
Jar 6		50				7.1	1.22	0.5
Duplic.								
Duplic.								

Purpose: standardized dosage of GAC Alum

Notes:

Coagulation Jar Test Data

Date: 1/25/00 **Time:** 12:00
Sampling Location: Central Lab Tap
Run #: 16

T (deg C): 14
pH: 8

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
min rpm
min rpm

Sample	Chemicals Added					Analysis Performed		Visual Observations
	$FeCl_3$ (mg/l)	Mahankal Alum (mg/l)				pH	turbidity	
Raw						8	3.31	Floc size (mm): 0
Jar 1		0				8	3.32	0
Jar 2		5				7.7	3.83	0
Jar 3		10				7.7	4.77	0
Jar 4		15				7.5	4.15	0.1
Jar 5		20				7.5	3.7	0.2
Jar 6		25				7.4	2.66	0.2
Duplic.								
Duplic.								

Purpose: standardized dosage of Mahankal Alum

Notes:

Coagulation Jar Test Data

Date: 1/25/00 **Time:** 1:05
Sampling Location: Central Lab Tap
Run #: 17

T (deg C): 14
pH: 7.7

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
min rpm
min rpm

Sample	Chemicals Added					Analysis Performed		Visual Observations
	$FeCl_3$ (mg/l)	Mahankal Alum (mg/l)				pH	turbidity	
Raw						7.7	7.47	Floc size (mm): 0
Jar 1		0				7.7	4.56	0
Jar 2		30				7.5	3.42	1.1
Jar 3		35				7.4	3.1	1.1
Jar 4		40				7.3	2.17	1.1
Jar 5		45				7.2	2.42	1.1
Jar 6		50				7.2	2.37	1.1
Duplic.								
Duplic.								

Purpose: standardized dosage of Mahankal Alum

Notes:

Coagulation Jar Test Data

Date: 1/25/00 **Time:** 2:15
Sampling Location: Central Lab Tap
Run #: 18

T (deg C): 16
pH: 7.9

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
___ min ___ rpm
___ min ___ rpm

	Chemicals Added					Analysis Performed		
Sample	$FeCl_3$ (mg/l)	Mahankal Alum (mg/l)				pH	turbidity	Visual Observations
Raw						7.9	4.35	Floc size (mm): 0
Jar 1		0				7.9	4.59	0
Jar 2		55				7.4	2.52	1.1
Jar 3		60				7.2	2.98	1.1
Jar 4		65				7.1	4.65	1.1
Jar 5		70				6.9	2.1	1.1
Jar 6								
Duplic.								
Duplic.								

Purpose: standardized dosage of Mahankal Alum

Notes:

Coagulation Jar Test Data

Date: 1/25/00 **Time:** 3:35
Sampling Location: Central Lab Tap
Run #: 19

T (deg C): 16
pH: 7.5

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: 30 min 0 rpm
___ min ___ rpm
___ min ___ rpm

	Chemicals Added					Analysis Performed		
Sample	$FeCl_3$ (mg/l)	Bansbari Alum (mg/l)				pH	turbidity	Visual Observations
Raw						7.5	9.8	Floc size (mm): 0
Jar 1		0				7.5	8.67	0
Jar 2		55				6.9	3.27	1.1
Jar 3		60				6.9	2.77	1.1
Jar 4		65				6.9	3.49	1.1
Jar 5		70				6.9	3.13	1.1
Jar 6		75				6.9	2.98	1.1
Duplic.								
Duplic.								

Purpose: standardized dosage of Bansbari Alum

Notes:

Appendix C: Settling Jar Test Data Sheets

Turbidity Measurements for Settling Jar Test Data

Date: 1/26/00 **Time:** 10:35 start settling
Sampling Location: Central Lab Tap
Run #: 1

T (deg C): 15
pH: 7.6 of raw

Mixing Regime:

rapid mix:	0.5 min	100 rpm
gentle mix:	10 min	30 rpm
settling:	min	0 rpm
	min	rpm
	min	rpm

Chemical	Turbidity (NTU) at Intervals Into Settling Phase				
Chemical	Blank	FeCl3	Alum	Alum	Alum
Dose (mg/l)	0	20	40	40	40
pH	7.6	7	7	7	7
Time					
10:35	6.72	8.4	15.7	16.6	6.99
10:40	5.82	0.98	11.5	10.1	4.55
10:45	5.61	0.75	8.93	5.09	2.78
10:50	5.35	0.67	6.41	3.38	2.26
10:55	5.31	0.63	4.8	3.1	2.17
11:00	5.18	0.72	4.35	2.41	1.66
11:05	5.1	0.6	3.46	1.51	1.16
11:10	5.04	0.65	2.51	1.61	0.93
11:15	5.24	0.6	2.06	1.35	0.87
11:20	5.11	0.58	1.46	1.2	0.76
11:25	4.85	0.61	1.35	1	0.79

Turbidity Measurements for Settling Jar Test Data

Date: 1/26/00 **Time:** 12:05 start settling
Sampling Location: Central Lab Tap
Run #: 2

T (deg C):

Mixing Regime:

rapid mix:	0.5 min	100 rpm
gentle mix:	10 min	30 rpm
settling:	min	0 rpm
	min	rpm
	min	rpm

Chemical	Turbidity (NTU) at Intervals Into Settling Phase				
Chemical	Blank	Bansbari Alum	Mahankal Alum	Bansbari Alum	Mahankal Alum
Dose (mg/l)	0	30	30	50	50
pH					
Time (min)	Before Dose: NTU				
0	4.55	11.2	11.3	15.4	16.1
5	4.54	10.6	11.2	15	14.4
10	4.57	9.68	10.6	14.4	13
15	4.66	9.64	8.86	10.8	9.44
20	4.49	9.67	8.98	7.98	8.99
25	4.53	7.46	7.39		
30					
35	4.39	4.79			
45	4.2	3.67	3.88	3.89	3.02
50					

Notes: The battery on the turidimeter was running low and the replacement batteries did not have enough power.
As a result, data is intermittent at times.

Turbidity Measurements for Settling Jar Test Data

Date: 1/27/00 **Time:** 9:55 start settling

Sampling Location: Central Lab Tap

Run #: 3

T (deg C): 16

Mixing Regime:

rapid mix:	0.5 min	100 rpm
gentle mix:	10 min	30 rpm
settling:	min	0 rpm
	min	rpm

Turbidity (NTU) at Intervals into Settling Phase

Chemical		Blank	FeCl3	Bansbari Alum	Bansbari Alum	Bansbari Alum	Bansbari Alum
Dose (mg/l)		0	20	25	30	35	40
pH		7.8	7	7.2	7.1	7.1	7
Time	Before Dose:	4.07					
10:05		4.18	5.96	9.7	>9.99	>9.99	>9.99
10:14		4.08	1.65	8.96	>9.99	>9.99	>9.99
10:20		4.06	1.24	8.42	8.19	>9.99	9.95
10:26		4.08	0.92	7.22	8.43	5.95	7.63
10:31		4.05	0.73	6.64	6.56	5.53	6.09
10:37		3.97	0.64	5.93	5.43	4.68	5.51
10:44		4.02	0.65	5.25	4.69	3.34	4.36
10:49		4.13	0.67	4.92	3.91	3.21	3.98
10:54		3.98	0.58	4.15	3.26	3.08	3.03
11:01		3.97	0.55	3.83	3.32	2.74	2.41
11:07		4.15	0.57	3.36	2.94	2.22	2.28
11:14		3.88	0.54	3.46	2.7	2.01	2.09
11:21		4	0.54	3.02	2.34	1.72	1.51
11:29		3.91	0.59	2.51	2.29	1.68	1.67
11:36		4.06	0.54	2.5	1.99	1.61	1.4
11:45		3.84	0.53	2.31	1.7	1.55	1.23
11:52		3.86	0.53	2.01	1.51	1.34	1.26
12:05		3.93	0.53	2	1.31	1.36	1.04
12:15		3.77	0.54	1.82	1.42	1.2	1.04
12:21		3.77	0.54	1.68	1.47	1.11	0.91

Notes: After replacing turbidimeter with new batteries, the turbidimeter does not recognize NTU measurements above 9.99. A notation of >9.99 is used.

Turbidity Measurements for Settling Jar Test Data

Date: 1/27/00 **Time:** 1:03 start settling
Sampling Location: Central Lab Tap
Run #: 4

T (deg C): ______

Mixing Regime:
rapid mix: 0.5 min 100 rpm
gentle mix: 10 min 30 rpm
settling: ____ min 0 rpm
____ min ____ rpm
____ min ____ rpm

	Turbidity (NTU) at Intervals into Settling Phase						
Chemical		Blank	Bansbari Alum	Bansbari Alum	Bansbari Alum	Bansbari Alum	Bansbari Alum
Dose (mg/l)		0	40	50	60	70	80
pH		7.8	7	6.8	6.8	6.7	6.7
Time (min)	Before Dose:	5.2	NTU				
1:14		5.67	>9.99	>9.99	>9.99	>9.99	>9.99
1:26		5.56	>9.99	>9.99	>9.99	>9.99	>9.99
2:00		5.57	7.34	4.9	5.51	5.93	4.47
2:31		5.04	3.01	1.91			
2:46		5.19	1.97	1.98	2.23	1.9	1.58

Notes: Battery in turbidimeter is extremely low on batteries. Takes only intermittent data. Blanks out a lot.

Multi-day Settling Test

Date: 1/24-1/26 **Time:** 16:00
Sampling Location: Central Lab Tap
Run #: 5

T (deg C): ______
pH: ______

Date	Time	Turbidity
24-Jan	4:10	4.91
25-Jan	4:00	3.69
26-Jan	4:10	3.52

Purpose: Determine the amount of settling over time of chemically untreated water.

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