Rocky Hill Water Situation Section 3.

Rocky Hill Ion Exchange - system design.

A. The Horsham experience.

At first sight Horsham did not seem particularly relevant to the Rocky Hill situation. Horsham Water Authority was one of the listed PFAS trouble spots in Pennsylvania, along with the nearby Naval Air Station Willow Grove.
They had high levels of PFOS and PFOA leading to the eventual closure of 5 wells and were forced to take action in 2016. Their solution was to introduce GAC adsorption filters.
As described in Section 1 page 5, that entails many tons of GAC and considerable ongoing expense, but is the usual approach.

During the last year there has been a degree of conformity between a limited number of States attempting to impose rigorous drinking water MCL standards for PFAS contaminants, along with other States that grouped classes of PFAS chemicals together under an EPA advisory limit of 70ppt. There were 16 States in all.
As of last July 2019, there remained 34 States that had no MCL regulations on PFAS. Pennsylvania was one of them. https://www.jdsupra.com/legalnews/state-by-state
Because of the many known PFAS problems in Pennsylvania there was a high level of community concern and criticism of the Pennsylvania lack of response.
https://www.ehn.org/delay-in-regulating-pennsylvania-pfas-2633596363.html
This was reflected in the Horsham Township community demanding full removal of PFAS contamination from their drinking water, rather than accepting conformity to some advisory 70ppt. This is cited as being a first for the water treatment industry in Pennsylvania and led to the pilot study with ion exchange as described in the previous Section 2. It was all created through Horsham community action.

The pilot study - **removal of trace PFAS using selective resin** - was exactly of interest for the Rocky Hill situation.
In addition, the assigned well (#10) for the pilot study was an excellent choice since the aquifer characteristics were fairly similar to ours.

Their original intention however was still to use the traditional GAC filtration approach and to use the resin only for clean up "polishing" of residual trace PFAS. If that had occurred, the study would not have been so fundamentally important to us.

It turned out they underestimated the large amount of GAC that was needed and so the study turned into an investigation of the ion exchange resin removing the PFAS contamination by itself – which is exactly what we wanted.

Horsham was in a lot of trouble, but they persevered and eventually came through with a crucially important and very successful solution to their PFAS problem.
There are very few, if any, direct studies of this type that are reported.
This is all relatively new.
Our PFAS solution is derived from this Horsham experience.

B. DOM and ion exchange

As described in Section 1 page 6, there is an overwhelming effect of dissolved organic material (DOM) on the adsorption process with GAC, which is the reason for early PFAS breakthrough when GAC is used for extraction of PFAS contaminants.

Therefore, since organic molecules are ionized in water, it was concluded that the effect of DOM would logically also apply to ion exchange, with the implication that the fixed ions of the exchange resin would be "swarmed" by anions from the DOM. We needed to know if this would be a serious problem in practice.

There have been a number of recent studies on the impact of DOM on ion exchange processes, motivated by an increasing interest in using ion exchange to remove PFAS from water sources, particularly the main river sources, and with ideas of in-situ brine soak regeneration of resin, PFAS concentrators, and elimination of down-time due to resin replacement in remedial field programs.

In the related paper by Dixit et al., the resin service life (in terms of operational bed volumes (BV)- namely volumes of the resin "bed") was investigated in the presence of background organic matter, using a system of batch stirred reactors in the laboratory.   https://www.doi.org/10.1016/j.watres.2020.116098
Conceptually, this was equivalent to recirculating an influent that was "spiked" with known PFAS constituents from prepared samples, and using water with known organic matter composition, through a weighed amount of resin for a predetermined time corresponding to a certain number of BVs. The resin would then be removed, filtered, and transferred to another identical reactor to continue the process (simulating a continuous influent – like an aquifer or river). There were extensive measurements of PFAS levels. Since multiple known PFAS chemicals (including Gen-X) were used, the uptake efficiency for the various fluoro-alkyls could be determined in terms of BV to saturation breakthrough (above 70ppt).

This was an extensive and careful study and the influence of DOM was clearly established. Using de-ionized water as reference (where BV was far in excess of 100,000) the BV was reduced down to around 28,000 in the case of PFOA when the DOM was at a level of 2.5mg/L (ppm), which is quite common in Canadian river water - (Suwannee River Natural Organic Matter at 5.0+/_ 0.1mg/L is used as a DOM standard). **There was a significant loading effect on the ion exchange resin due to ionized organic molecules. It is essential to reduce DOM.**

They also found that resin breakthrough (above 70ppt) for all PFAS corresponded to above 90% resin site saturation. So the resin (Purolite A 860 in this case) was very efficient for all PFASs. This included Gen-X, which was an important finding.

There have been various claims made about the superior efficiency of ion exchange resin over GAC. It is important however to appreciate that for GAC a long contact time is required, not because of GAC limitations but because of the physics of the adsorption process and the short range molecular forces.
Many comparative efficiency studies relating GAC to ion exchange resin do not allow for sufficient required contact time for effective GAC adsorption.

In spite of this, there is clear evidence of very high efficiency for ion exchange resins. This can be attributed most likely to the increased sophistication in the production of the resin materials and perhaps introducing the technology of ion implantation to put multitudes of "receptors" (fixed positive charged ions) embedded on the resin spheres in the manufacturing process.
The number of **ion** "trapping sites" (now using GAC terminology) for ion exchange resin is now indicated to be quite enormous and comparable to, or perhaps even exceeding, the number of trapping sites with activated carbon.

The Horsham well # 10 had a moderately low DOM level of 0.2mg/L (200 ppb) which then accounts for the observed capacity (above 639 days) of the resin in the pilot study, and the observed excellent removal of **all** PFAS components by the ion exchange resin is also consistent with the results of the Dixit study.
Aquifer water is always lower in DOM and in general ground water pollutants (not of course local pollutants) than river and surface waters. The aquifer introduces filtration adsorption to the water source.

C. Aeration – the Rocky Hill advantage.

There are limited ways to remove dissolved organic matter (DOM) from the water supply. They are basically chemical coagulation (such as by using alum – aluminum sulfate – as coagulant) activated carbon adsorption, ion exchange, biological (bacterial) degradation, and finally **aeration.**
Aeration is a mainstream technique to accelerate solid waste degradation in waste treatment plants, as a result of oxidation. It is less commonly known in water treatment applications, other than as a method to remove carbon dioxide or to remove (by oxidation) contaminants such as iron and manganese often found in well waters, and found for example in many places in Florida.
In practice however aeration also provides a very good method of removing volatile organic compound (VOC) contaminants in drinking water, based on vapor pressure.

This is the basis of the Rocky Hill water treatment facility. It is a two-stage aeration system designed to remove volatile organic matter from the water supply down to non-detect (ND) levels.
The Rocky Hill aeration system therefore removes a definite fraction of the dissolved organic matter (DOM) in the water (namely the VOC component).

In the case of the ion exchange process, reduction of DOM in the water supply is critically important and is expected to significantly extend the operational times between required resin replenishments.
In the Rocky Hill system the ion exchange filter would therefore be located between the two aeration stages, located after the first aeration column which removes the majority of VOC (98.6% for TCE). At this location there is access to the water stream at low pressure between the storage tanks, and it is the place to insert ion exchange filters into the process.

The ion exchange filter would actually consist of two filter modules operating in lead-lag configuration. We could then refer to lead and lag modules.

Because of the needed interchangeability, they are identical. They are properly designed industrial grade filter units, in this case using ion exchange resin which would be Purofine PFA694E manufactured by Purolite and as used in the Horsham study. It is advertised as being specifically intended for PFAS removal.
Also it is … " a uniform grade resin with beads of similar size and will not require backwashing for classification/stratification before use"…
This is actually quite important. Filters with bulk media generally need to have a backwash procedure to settle and stratify the filter bed and prevent channeling. This is all avoided with the use of this resin.

D. System design

The design features need to be centered around maximizing filter efficiency since that will extend the operational time between needed replacement of ion exchange resin, and will amortize operational costs over a longer time period, so we need to maximize efficiency and determine the optimum system capacity.

In water systems, capacity is synonymous with storage, not with flow rate.
The Rocky Hill system (like many small rural systems) operates on a demand-supply scheme based around a duty cycle operation.
The system is not operating all the time. It is not working very much during late evening and night hours for example. Most systems (both electronic as well as mechanical) that involve duty cycle operation are generally designed around 50% duty cycle.

Since the system operation is not continuous, the capacity depends on storage.
In most systems like Rocky Hill, the storage is determined by the main storage tank which also provides the water pressure at all times.
Extra capacity (usage) can be accommodated for by adding either distributed or POU (point of use) storage.
A good example of POU storage is the use of water tower units on buildings in major cities. Distributed storage is employed by larger water systems that use water "farms" supplied from various sources that pump to determined pressure limits.
These systems are generally running continuously.
With duty cycle operation the system has to be physically sized to be able to pump at levels higher than the averaged pumping rate, and with a 50% duty cycle it has to be able to pump at twice the average rate.
This basic fact is another clear reason why GAC adsorption filters are not viable for facilities like Rocky Hill working under duty cycle. The GAC filter system has to be sized for the maximum pumping rate and the size requirement then becomes quite large (doubled).

By contrast, the ion exchange process is not based on adsorption and does not have this major limitation of required contact time. The ion exchange filters can therefore be much smaller. The sizing then depends on more physical limitations, like working space and ease of handling, within the goal of optimizing the bed volume (BV) to increase the operational time of the filters and the system efficiency, and to reduce overall long term operating costs.

E. Sizing of the ion exchange filters.

The starting point is the estimate of ion exchange capacity in terms of time to breakthrough. This is the important value of the Horsham pilot study.
The Horsham system operated with 50 gallons per minute continuous pumping and used a resin bed volume (BV) of 20 cubic feet, 150 gallons.
From the Horsham data and Fig 3 of the report, the output from the filter showed a blip of 2ppt for PFOA at day 639 of the pilot study (1.75 years) and, based on the assumption that this indicated breakthrough, the pilot study was stopped.
It is stated that at that point the operating capacity of the total volume of resin was equivalent to treating 329,000 bed volumes (BV).

We can now choose an appropriate volume of resin and iterate to get an overall acceptable sizing and breakthrough time for our intended system design.
Purolite sells several levels of bulk packaging of PFA649E resin, including the 1cubic meter "supersack". The bulk quantity is then 1000 liters (35.3 cubic feet, 264 gallons). We have chosen this 1000 liter volume for the resin for each filter module.

On the basis of 329,000 BVs with a BV of 264 gallons and an average pumping rate of 50 gallons per minute, the time to breakthrough is then 3.3 years for the lead module in our lead-lag configuration.

In the Horsham study report their projected design for a permanent full-scale system was based on a "very conservative" estimate of 350,000 bed volumes rather than the 329,000 BV mentioned above.
This is probably because the 2ppt blip at day 639 does not look like breakthrough, which normally shows as a progressive increase in measured contaminant output up to a designated cut off level (such as a MCL value).
Also the blip at 2ppt is basically at the non-detectable (ND) level.
It is a pity they did not continue further to establish the clear breakthrough point.

On the basis of 350,000 bed volumes, the time to PFAS breakthrough for our 1000 liter volume of resin then becomes 3.52 years. This is the sort of time frame we are aiming for. Note that this is just for the lead filter. The lag filter is still processing with an output contaminant level of zero.

It should be noted that in these estimates we are not including anything related to duty cycle on the factors in the ion exchange process. Because we are not dealing with adsorption, there are no considered effects on the process related to things like required contact time – which directly relates to the pumping rate.
The duration time to breakthrough is therefore calculated using the average pumping rate over time.
The Rocky Hill Water Facility pumps around 26 million gallons of water per year.
This equates to just under 50 gallons per minute, and therefore compares to a system pumping continuously at 50 gallons per minute – exactly like the Horsham study with well #10.
With a resin volume of 1000 liters (264 gallons) we would have an EBCT of 2.6 minutes for each filter with 50% duty cycle pumping at 100 gallons per minute.

We are therefore involving some measurable EBCT (2.6 minutes each filter) even though contact time is not considered a required factor in the ion exchange process.

F. Filter description and building extension.

Because the Rocky Hill system operates on duty cycle and not continuous flow, there will be times of stationary water in the filters. To avoid problems of winter freezing the filter tanks cannot be located outside.
In any case, they need to be located with access to the storage tanks of the aeration stacks, as previously described.

The filters will be 4 feet in diameter and 6 feet high. This is about the limit of a manageable size. These will not simply be tanks with inlet and outlet pipes, but industrial grade filter units designed for high efficiency filtering in commercial and industrial applications. We need to have maximum filtering efficiency to take full advantage of the ion exchange resin.

The intention is that the filters are loaded on site, which requires them to be moveable into position when loaded. Interconnection would be managed using PVC union couplings with selected sections of PVC pipe to accommodate various configurations of the lead-lag operation. We would avoid rigid fixed piping layouts with multiple valves. The whole idea of a modular approach is flexibility.

There is inadequate space in the aeration building to locate these filters, a building extension is required. This extension would communicate with the aeration area. It would require a garage type door so the filter tank can be moved out onto an external loading pad. All this needs to be worked out in detail as a significant part of the project.

G. Cost estimate.

We are not in a position to issue RFQs (request for quotation) for accurate cost information, and the manufacturer's costs are generally not openly advertised. However it is possible to get cost estimates from internet sources and from quoted prices from various distributors. The Horsham study also discusses costs in the design of a proposed full sized system for Horsham Township.

The indicated internet cost of PFAS selective resin is between $5 and $7 per liter, and with a required 300 liter minimum volume order.
The Horsham study included around 1080 liters in their proposed full scale system design and cited a cost --" including replacement media, labor, trucking "– of $8000 for ion exchange. We therefore assume the same estimated cost of $8000 for the PFA 694E resin from Purolite (1000 liters) - which would apply to each filter.

The cost of the filter tanks from various distributor sites has varied from $2900 to over $3500 each, and the cost depends on certain specified features and optional accessories.

These fiberglass tanks are fairly large and some of the accessories are quite useful, such as a lateral manhole cover for access and inspection at the time of resin loading and replacement. A valve kit costs around $350 for each filter. So we assume $4500 as an actual cost for each filter unit.

It should be noted that the cost for the filters is a one-off cost. The filters are then owned by us, and there are no ongoing rental charges.
This is a far different situation than for the very high costs of the large filter tanks associated with GAC systems. They are heavy external tanks, completely different.

The cost estimate is then around $9000 for the two filter tanks, and $16000 for the 2X 1000 liters of Purolite PFA 694E ion exchange resin, with sum total $25,000.

On a long-term basis, a recurring cost would be resin replacement in the lead filter, estimated around every 4 years. We assume there will be benefits (extended operational time) due to the DOM reduction by the Rocky Hill aeration. This cost estimate would then be $8000 for replacement resin every 4 years.

The lag filter would have been maintaining zero level PFAS output in the drinking water during this time, and then would be moved into the lead filter position. The newly recharged (lead) filter would then be relocated into the lag filter position.
It is important that this lead-lag exchange protocol is rigorously maintained.

The main cost item for the project will then become the construction of the extension building. There are many ways in which this can be achieved, and we have not included the extension building as part of the overall cost analysis at this time.

H. Implementation.

The full information content of Section 1 through Section 3 is presented for download on the website **www.rockyhillwater2020.com** and is intended for general access by the Rocky Hill community.
It is intended to be available for everyone in the community to read about and understand the PFAS situation in Rocky Hill and the various possible solutions that can be employed to remove PFAS contamination from water supplies, and their various disadvantages and advantages.
It is suggested and hoped that the Rocky Hill community would decide to totally remove PFAS contamination from the water supply.

A method of PFAS removal has been analyzed and presented that is particularly well suited to the Rocky Hill situation which has trace level PFAS contamination and also has an aeration system integrated into the Water Facility operation. The method uses ion exchange.

This all culminates in an effective method of PFAS elimination with very low cost compared to the other generally used methods.
The cost would be more than covered by revenues from just one year of water facility operation.

The proposed system design needs to be thoroughly evaluated by the Borough Council and the Rocky Hill community, and approved.

This is a Rocky Hill community problem. It will be funded by the community and therefore it needs to be fully understood and supported and approved by the Rocky Hill community. The project decision is a Borough decision.

The NJ DEP does not advocate or attempt to enforce any solutions to such problems. They will be as helpful as possible, but suggesting solutions for these sorts of problems is not their job, and obviously cannot be their responsibility. Their concern is that the project fulfills all the necessary requirements and regulations.

This is how a similar (but much worse) problem with heavy TCE contamination was resolved in the 1980 time period, when the Rocky Hill aeration system was built.

A small task force group then needs to be set up to firmly hammer out all the involved details and costs to the point of specific item procurement and bidding, with contact and input as required from the Borough Council and community, and every member of the task force actively contributing expertise and support in different areas of the project, and with specific agreed assignments.

In the 1980's situation every effort was made to involve local business and local contractors in the construction phase.
The system design at that time was far more complicated than this one, which is fairly straightforward and is routine in comparison.

Also, in this case, the way forward has already been shown by the extremely valuable two-year Horsham pilot study – the topic of Section 2.

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