The Rocky Hill Water Facility.

Section 7. Duty Cycle Operation -- and what this actually means.

As proposals are evaluated to remove PFAS from the Rocky Hill water supply, it must be understood that our water facility operates under duty cycle.
The implications of duty cycle operation are far reaching, and it determines whether proposed systems will work or not, and how the systems should be designed.

The topics covered in this **Section 7** relate to:
1) The basis of Duty Cycle operation; 2) The Rocky Hill water distribution system; 3) The absence of need for extra wells or storage towers; and 4) The historical context that Rocky Hill has fulfilled the NJDEP required "ability to provide" water to the Rocky Hill community for the past 39 years under the NJDEP watch.
This section also introduces ion exchange, the Rocky Hill PFAS contamination problem, and the best method of achieving PFAS remediation.

The local press has reported a $2.3 million Rocky Hill loan application to address Firm Capacity, with extra well and secondary pumping facility, as well as the PFAS remediation question, and some infrastructure work.
These issues must be understood before the Rocky Hill citizens incur such debt.
The remediation system proposal(s) must be scientifically sound, must work, and must be fiscally responsible.
These issues are dissected in this **Section 7**, and also in the following **Section 8.**

Duty Cycle.

The Rocky Hill water facility operates as a duty cycle system which pumps water at 200gpm (gallons per minute) to a storage tower through an aeration system. This is a good pumping capacity, and there are no indications of lack of water to sustain such operation.
The essential requirement of duty cycle water systems is a solid and productive water supply. The aquifer supplying water for the Rocky Hill well is extensively tested and documented. The turbidity is extremely low, the water is crystal clear, and there is no need for post filtering or chemical treatments. This testifies to a very good and extensive aquifer, with very effective molecular adsorption throughout the aquifer. The dissolved organic matter content is at the characteristically low level of such aquifer water, in the region of 200 parts per billion. The water quality is excellent. Rocky Hill uses 26 million gallons of water a year.
In the 2016 EPA report on the TCE remediation program (dating back to the 1980 time period) for the Rocky Hill aquifer, more than 300 million gallons of water had been pumped from the aquifer and discharged to the Montgomery Township storm drains in a "pump and dump" operation which is still ongoing at a continuous 44gpm (close to 23 million gallons per year). So the aquifer is quite plentiful.

The duty cycle operation can be explained as follows: Assume that the storage tank is being drained at an average rate of 50 gallons per minute. When it reaches a

predetermined **L**ow level it is refilled. The storage tank is refilled at 200 gallons per minute, and the system turns OFF at a designated **H**igh Level in the storage tank.
So, it fills up 4 x faster than it drains. The system therefore is only refill pumping for 25% of the drain cycle time. This is referred to as a 25% duty cycle operation. The duty cycle, which is the ratio of the demand rate to the pumping rate (200gpm), is constantly changing, depending on the demand.
The water facility is not pumping continuously, it is cycling ON and OFF in an automatic duty cycle operation.
It is necessary that the pumping capability in such systems **always exceeds the peak demand**. That is the basic essential requirement.
The water storage tank, maintained full, provides a water reserve to average out peak demand fluctuations. The water reserve between **L** and **H** levels prevents short cycling of the well pump. Duty cycle systems are designed to produce more than the demand, and therefore do not need more water supply.
In fact, such systems cannot incorporate any extra wells in any simple manner into their automatic duty cycle operation.
That is a distinct characteristic of duty cycle systems. One well. No extra wells.

One thing to be appreciated in systems such as Rocky Hill's is the simplicity and effectiveness of gravity feed using a centralized water storage tank.
The water pressure is determined by the height of the water column, and this is continually maintained between the **Low** and **High** sensing levels about 5 or 6 feet apart at the top of the tank.
Water is essentially an incompressible fluid and everyone all over the Borough, tapping into the water supply line from the storage tank, has the same water pressure. No water pumps are needed by anyone to generate water pressure.

For laminar (non turbulent) flow of liquid in a pipe the flow rate is dependent on the head pressure and on the pipe diameter (proportional to the 4th power of the internal pipe diameter) and inversely dependent on the pipe length.
If the diameter of the pipe is doubled the flow rate is increased by factor 16, and if the pipe length is doubled, the flow rate is halved.
This is known as the Poiseuille formula or the Hagen-Poiseuille Law.

In the case of a water supply, the resulting flow rate does not depend on the volume of the water storage tank, it only depends on the water pressure (which is the height of the water column) and on the length and the diameter of the pipework.

<u>The Rocky Hill water distribution system.</u>

There are several types of water distribution systems. The simplest one that is generally used with small Municipal systems similar to Rocky Hill's is often referred to as the "dead-end" system or the tree distribution system, or the leaf system.
It is the system used in nature – as in blood circulation systems, based on the arterial and vascular network. The Poiseuille formula applies.

The water distribution system is based on the use of a main pipe with sub mains dividing into branches with service connections. There are dead ends at line terminals, which require periodic flushing.
With a simple distribution system of fixed pipe diameter, it is apparent that the flow rate will be lower for water customers at the end of a long line and (with Princeton Avenue as an example) the actual effective end of the line could possibly be as much as ¾ to 1 mile away from the storage tank.

It is also apparent that simply adding another municipal storage tower to the water system is not going to improve the water flow rate situation.
Adding another storage tower of the same height does not change the system pressure and, using the same distribution network, it does not change anything. With reduced flow rate at the end of a long line, any further additional branch distributions in that area will make the situation worse for everyone in that section of the distribution network. This is introducing the concept and realization that simple distribution networks of this type (like Rocky Hill's) have a natural size limitation. There are water pumping limits associated with such network systems. In the case of Rocky Hill, there is a permit-based pumping limit of 37 million gallons a year issued by the NJDEP. This then relates to a limit in the number of water users. At this limit the Rocky Hill water distribution system is expected to have trouble supplying adequate flow rate to outlying residents.

If an assumed water customer at the end of a long line actually had a low and inadequate water flow rate, the remedy (providing a pressurized water flow) would be to add storage in the form of some POU (point of use) storage and to use a pressure tank with a small booster pump. This is essentially a water supply method still using the distribution network, but adding a pressure tank and booster pump on an individual basis.

In summary:
***Adding more wells to the Rocky Hill water facility (operating as a duty cycle system) is not possible. Also, adding any further water storage towers to the Rocky Hill water facility with the existing water distribution network is not meaningful – not changing anything*.**

<u>Firm Capacity</u>

The Firm Capacity question keeps on re-appearing as a result of an underlying belief that the NJDEP requires Rocky Hill to have another extra back-up well and pumping facility as a condition of operation.
This is completely erroneous. They do not. Nowhere is it stated in any NJDEP literature or in any documentation on the matter that a separate, extra, well and pumping facility is needed as a "Firm Capacity" requirement for operation.
This has already been discussed at length in **Section 5** presented on the website www.rockyhillwater2020.com - but apparently still seems to persist.

Rocky Hill constructed an aeration system in 1982 to solve a major TCE contamination problem, and Firm Capacity was also addressed at that time.
The Rocky Hill water facility has been in operation for the past 39 years, with full NJDEP knowledge, and successfully addressing the firm capacity issue.

The first lesson learned was that the EPA (and DEP State affiliates) do not tell Rocky Hill (or anyone else) how to do things. That is not their job. They specify what is required and what has to be done, but not how to functionally do it – that is the responsibility of the local community and administration.
Rocky Hill experienced this in the 1980 time period with the severe TCE contamination of the water supply and the eventual construction of the aeration system to remove the volatile organic contaminants.
The EPA was asked for advice (from their data base and experience on the very widespread VOC contamination issue) on how Rocky Hill might best design and incorporate aeration technology into the water system.
The answer received was that the EPA was legally mandated to safeguard the environment and the public health – and could not get involved in specific technical problems and their solutions. It was not the EPA responsibility to instruct or advise on how things should be done. That was a Rocky Hill responsibility.
That was correct, and made total sense. They could not get involved in such details. By doing so they would be undertaking responsibility and involvement in issues that could become extensive and never–ending. Such involvements would also be fundamentally beyond their legal mandate.
So, the NJDEP did not imply or suggest any such construction of another backup well system in Rocky Hill for Firm Capacity.
The term Firm Capacity is very carefully defined by the DEP as the "physical ability to provide treated water at adequate pressure when the largest pumping unit or treatment unit is out of service."… No mention is made anywhere of extra wells being needed by anybody. The key legal requirement to be met is having the …
…..."**physical ability to provide** …"
How this is done is entirely a Rocky Hill problem – and it relates to having a required physical backup ability. That is what we addressed in 1982.

There also was need for a common sense and logical analysis of what a suggested secondary back-up water facility would actually mean and involve.
Realistically, the Rocky Hill aquifer is not going to suddenly fail. The supposed system failure that was being considered related entirely to the failure of the well pump unit. What is therefore involved is backup redundancy of the well pump.

The industrial and commercial quality submersible well pump is a highly detailed and especially well designed piece of equipment.
These pumps use multiple volute stages, machined from stainless steel, and also sometimes Titanium, and the units as a whole are designed to be rugged, corrosion resistant, and very reliable. They are very expensive in the pumping range that is required in the Rocky Hill Water Facility.

The typical reported average field use of submersible pumps of this performance and quality from the established industrial U.S. manufacturers is around 25 to 30 years. This is referred to as the MTBF (mean time between failure) for such units.

Rocky Hill had originally built and installed a separate well and well pump with a small well house to act as the “backup system”, and it was never used.
In the 1980 time frame (when the aeration system was being built) the small well house was being vandalized and it was decided that the backup well should be capped and sealed and the well house demolished.
That was a Rocky Hill decision, unrelated to the construction of the aeration system.
This is all explained in **Section 5 (page 8)** on the above mentioned website.

There is now, at the present time, a Rocky Hill loan application for $2.3 million that includes, as a main Firm Capacity line item, the proposed construction of another (secondary) Rocky Hill water facility to simply backup a well pump component with a MTBF of around 25 to 30 years.

This obviously has to be always rationally justified against a planned replacement of the well pump unit, and it was decided back in 1982 to incorporate and employ a well pump replacement procedure.
The Rocky Hill Water Facility has not included any redundant well pump for the past 39 years and without any significant problems (and with full DEP knowledge and without any form of comment or complaint). That was a deliberate Rocky Hill decision at that time.

There was an actual well pump failure event some years ago, detected as a major system fault, with an alarm telephone contact.
A replacement submersible pump was installed and the system fully re-activated in just over two (working) days. The well pump was lifted out of the well casing through an existing overhead trap door using a lifting crane and cable drum winch. The outlet water pipe from the pump can be decoupled and removed in sections as it is withdrawn. This is a standard operational procedure in the water industry.
As is stated in **Section 5**, this replacement procedure might have been done a little quicker if a replacement submersible well pump had been carried in inventory. However, this would have involved carrying in inventory a very expensive submersible well pump for 25 to 30 years, and it was decided not to do so.

Rocky Hill relies extensively on the traditional cooperation with the South Brunswick Water Authority, and on the expertise of their employee who is our water Superintendent. They have many wells and pumping systems and know all the procedures and how to rapidly secure standard parts and how to activate needed equipment when there are problems. That involvement is an important and integral part of the Rocky Hill Water Facility back-up redundancy strategy, which is all described in **Section 5**.
The Rocky Hill Water Facility has operated autonomously (totally unattended) for the last 39 years very successfully and without any significant disruption or lack of service to the Rocky Hill community. There has not been any lack of backup ability.

For the Rocky Hill Water Facility, the Firm Capacity exists in its design and operational protocol, and its backup ability, and is not a real concern.

Part of the confusion related to Firm Capacity undoubtedly relates to the NJDEP document entitled Public Water System Deficit /Surplus for the Rocky Hill Water Facility (PWSID 1817001) http://www.nj.gov/dep/watersupply/pws.htm
This document (viewed by entering **1817001**) indicates that Rocky Hill has a mathematically derived daily water deficit of 88,000 gallons, and a Firm Capacity of Zero – because it only has one well.
There is a basic lack of appreciation in this NJDEP document that the Rocky Hill Water Facility is a duty cycle system, and therefore only ever has one well.
Also, the Rocky Hill duty cycle system is based on the demand - supply operation, and there is no water deficit.
The Rocky Hill Water Facility is **not** a pressurized continuous pumping system capable of working with multiple wells – which is what this document assumes.
Also, in the Glossary of Terms for this document, Firm Capacity is defined as:
" **adequate pumping equipment** " – which says it all.
In spite of all this, the myth of a required extra well and pumping facility to meet a Firm Capacity need to back up the well pump still seems to persist for some reason – and to the point of now becoming a line item in a $2.3 million loan application.

In summary:
Rocky Hill does not need to sink another well (which would anyway be in the same aquifer) or to construct another pumping facility (with its own expensive pumping unit) simply to back up a well pump unit with a MTBF of 25 to 30 years.

Additionally, and most importantly, the Rocky Hill Water Facility (operating under duty cycle) cannot incorporate extra wells into its normal operation. Therefore, any new separate pumping facility would be sitting around unused for many years waiting for a main system well pump failure to occur. Rocky Hill has been through all of this before with the original "back-up" water facility that was never used, and which was demolished in 1982. One should learn from past experience.

The Rocky Hill PFAS contamination situation.

The Rocky Hill water supply has quite low (trace) levels of the larger PFAS molecules. It meets the MCL levels now legally required for PFNA and PFOA and is out of compliance only for PFOS **[Section 1 pages 2&3]** by a few parts per trillion. The Rocky Hill emphasis however should not be centered around getting compliance for PFOS, but in totally eliminating **ALL** such PFAS contaminants.

The only PFAS testing conducted so far is based around 3 PFAS molecules PFNA, PFOA, and PFOS. These are the longer carbon chain C9 and C8 molecules that are now largely phased out – but of course still exist in the environment. These are all "forever" chemicals, essentially indestructible.

The really nasty PFAS chemicals are the C4 and C6 carbon chain molecules that originally were introduced to replace the heavier ones in the year 2000.
These smaller, lighter, PFAS molecules are more water soluble than the others. PFBS, a replacement for PFOS, is highly soluble in water. Their general water solubility means that all PFAS chemicals are present in ground water but the more soluble ones are very readily assimilated into fruit and vegetables and animal feedstock, and so are increasingly present in the human food chain and are a very serious health concern.
It is inevitable, only a matter of time, before the list of PFAS chemicals that need to be tested for and removed will be increased. Their presence and danger is already known. PFAS contaminants are present everywhere in water and therefore in cell structures and are measured in human blood serum all across the world. This information is basic to the many toxicology studies that have all recommended certain Maximum Contaminant Levels (MCL values) for PFAS in drinking water, based on a lifetime exposure to them.
Although these MCL numbers cannot be precise, they are all at the trace levels of parts per trillion in water and they clearly indicate the very serious concerns about cellular damage at the molecular level.
The PFAS chemicals are virtually indestructible, not biodegradable, and their effects steadily accumulate in the body.
That is why they should all be totally eliminated from the Rocky Hill water supply.

PFAS remediation.

A solution to the Rocky Hill PFAS contamination problem was actually proposed over a year ago, in Nov 2020.
A system design for Rocky Hill was described in **Section 3** and posted on the website **www.rockyhillwater2020.com** for community review.
A flyer was previously circulated to the community to promote the website.

The design is based on the simple addition of two ion exchange filter units to the existing aeration stages of the Rocky Hill water system, and is done at quite low cost.
The use of PFAS selective anion exchange resin is the only viable method at present of totally removing all PFAS contaminants from the Rocky Hill water.
The design and construction of this PFAS remediation system is described in more detail in the following **Section 8.**

Is ion exchange a filtration process. ?

No, not really. Nor is GAC molecular adsorption.
The classical filtration process is associated with the use of sieves or mesh grids, or sand or other filters based on grain size, to block passage in solution of anything having a larger size.
Fine grain sand can filter down to around 20 microns in size, and powdered zeolites or diatom (DE - diatomaceous earth) down to around 3 microns (thousandths of mm) but molecular dimensions are very much lower – very sub micron. Filters of sub micron membranes with the use of water at high pressures, can remove

molecular level contaminants using the classical filtration process – but that is beyond the scope of feasibility for Rocky Hill and the associated PFAS remediation.

The GAC (granular activated carbon) "filters" that are generally used in removing molecular impurities from water are actually using the molecular adsorption process, which is a distinct physical surface effect process requiring very thin water films and very low flow rates to generate the conditions for close molecular contact required by very short range molecular attraction forces. So, a distinct physical process (molecular adsorption) is involved. This is not simple classical filtration.

With some large water facilities using such GAC adsorption, the activated carbon is powdered and used in settlement beds where water is stationary or flowing very slowly over the carbon, which is slowly churned by rotating auger paddles to maximize contact area. With water facilities dealing with significant water flow rates, the only available approach is to use extremely large volumes of GAC so as to pass the water through GAC for as long as possible to get the overall contact times that are needed for molecular adsorption.
This is the reason behind the use of the EBCT (Empty Bed Contact Time) parameter, relating water flow rate to the needed volume of GAC filter material. For GAC it is determined that EBCT should be 10 to 20 **minutes** for an efficient molecular adsorption process. This means that for a flow rate of 100 gallons per minute, a large volume of 1000 gallons to 2000 gallons of GAC is required for the GAC filter.

The GAC molecular adsorption process is a fundamentally slow overall process because of this necessary contact time, and basically is not compatible with duty cycle system operation. The molecular adsorption process cannot accommodate to time variant water flow, and always has to be related to the maximum flow rate.

Ion exchange is a completely different process that relates to electrostatic attraction and the interaction and exchange of ions in solution, and so is also not classical filtration. The ion exchange process is electrostatic and the forces involved are longer range and much stronger than the short range and weak molecular forces that are responsible for molecular adsorption.

Soluble materials dissociate in water to form ions, which are mobile in solution.
As a known example, salt NaCl dissolves and dissociates into Na + and Cl – ions and the positive charge cations and the negative charge anions are mobile in solution.
In the ion exchange resin structure, selected positive charge cation groups are embedded in very large numbers into the resin beads of the ion exchange resin.
They are fixed embedded cations, and are not going to migrate anywhere. All these embedded cations are linked to anions when the resin is initially "activated" – generally by saturation with brine (NaCl) solution having the mobile Cl– anions.
If the positive charged cation on the resin was mobile the situation would then represent mobile cations with mobile Cl– anions when in solution. However, these cations are fixed embedded in the resin and are not mobile. The mobile Cl– anion can move away but then the related fixed positive charge cation is exposed and another mobile anion in solution (hopefully an anion that is part of a PFAS

contaminant molecule) can rapidly attach itself to the fixed positive charge cation. The resin has then **exchanged** anions. This is performed by all the embedded cations.

This is a unique process. A chemical equation can be written for it in which the anion from solution exchanges with the mobile Cl– anion of the resin, with the mobile Cl– anion then entering solution.
The chemical equation has to involve charge balance and so involves valency, and is referred to as being stoichiometric when balanced. This is not classical filtration. The anion exchange process is therefore a chemical reaction involving exchange of anions in solution. It only relates to exchange of anions, no chemical bonds are broken, and the exchange process can be very fast.

This is a completely different situation to that of molecular adsorption (which in implementation is very slow) and the electrostatic ion exchange process becomes of fundamental importance in the duty cycle operation of the Rocky Hill water facility and in the Rocky Hill PFAS remediation. Complete removal of PFAS contamination absolutely requires the use of the ion exchange process. This is covered in more detail in the following **Section 8.**

In practice, things can get somewhat more complicated with the ion exchange process because the resin gel beads are porous and have a significant contact surface area (both internal and external). Since the resin polymer is hydrophobic, the ion exchange resin has excellent molecular adsorption properties. Consequently, the ion exchange resin exhibits both the electrostatic ion exchange process and the molecular adsorption process, even though they are completely different, polar opposite, processes.
The ion exchange process is fast, while the molecular adsorption process is slow. The ion exchange process involves strong, long-range, electrostatic forces while the molecular adsorption process uses the short range, weak, molecular attraction forces. And, they are both acting together within the ion exchange resin.

This molecular adsorption capability can in some respects be considered as an extra unrelated bonus for the overall ion exchange process.
The molecular adsorption has nothing to do with the fixed embedded cations, and would still exist if those positive charge cation groups were never included in the resin bead structure. The electrostatic and adsorption processes are always there and cannot be turned off. They only cease when their processes are saturated. Which of the processes dominates depends entirely on the situation.

Fortunately for Rocky Hill, with low contaminant levels, the process is entirely electrostatic, and only involves anion exchange. This is the Rocky Hill situation. It was also the situation for the Horsham study.

This all becomes particularly important for duty cycle operation systems, and impacts the amount of ion exchange resin that is needed, and the operational time of the resin material, as well as the overall fiscal and operational viability of the whole

PFAS remediation effort. These questions are more specifically addressed in the following **Section 8.**

<u>Conclusion</u>.

This **Section 7** has explained how the duty cycle mode of operation works in the Rocky Hill water facility, and why the Rocky Hill water system cannot incorporate extra wells or storage towers.
This section has also explained the practical limitations imposed on the water system by the Rocky Hill water distribution network as well as why the persistent myth of a required additional well and additional pumping facility to fulfill a Firm Capacity need for the Rocky Hill water facility does not apply, and does not really exist.
The question is then raised why Firm Capacity has now become an included line item in a $2.3 million loan application to justify constructing another secondary water facility to simply backup the Rocky Hill well pump.

The PFAS contamination situation has been outlined, with the belief that Rocky Hill should aim for complete removal of PFAS contamination from the water supply. This absolutely requires the use of the ion exchange process, and directly relates to the remediation system proposed over a year ago in November 2020, as described in **Section 3** on the website. This system was based on the groundbreaking study of PFAS removal in a municipal water system in Horsham, Pa. (outlined in **Section 2**) and which is fully and directly applicable to the Rocky Hill situation.

The important working details of the anion exchange process, and the construction details and costs of the proposed PFAS remediation system for Rocky Hill are covered in the following **Section 8.**

Ivor Taylor. Dec 10. 2021.