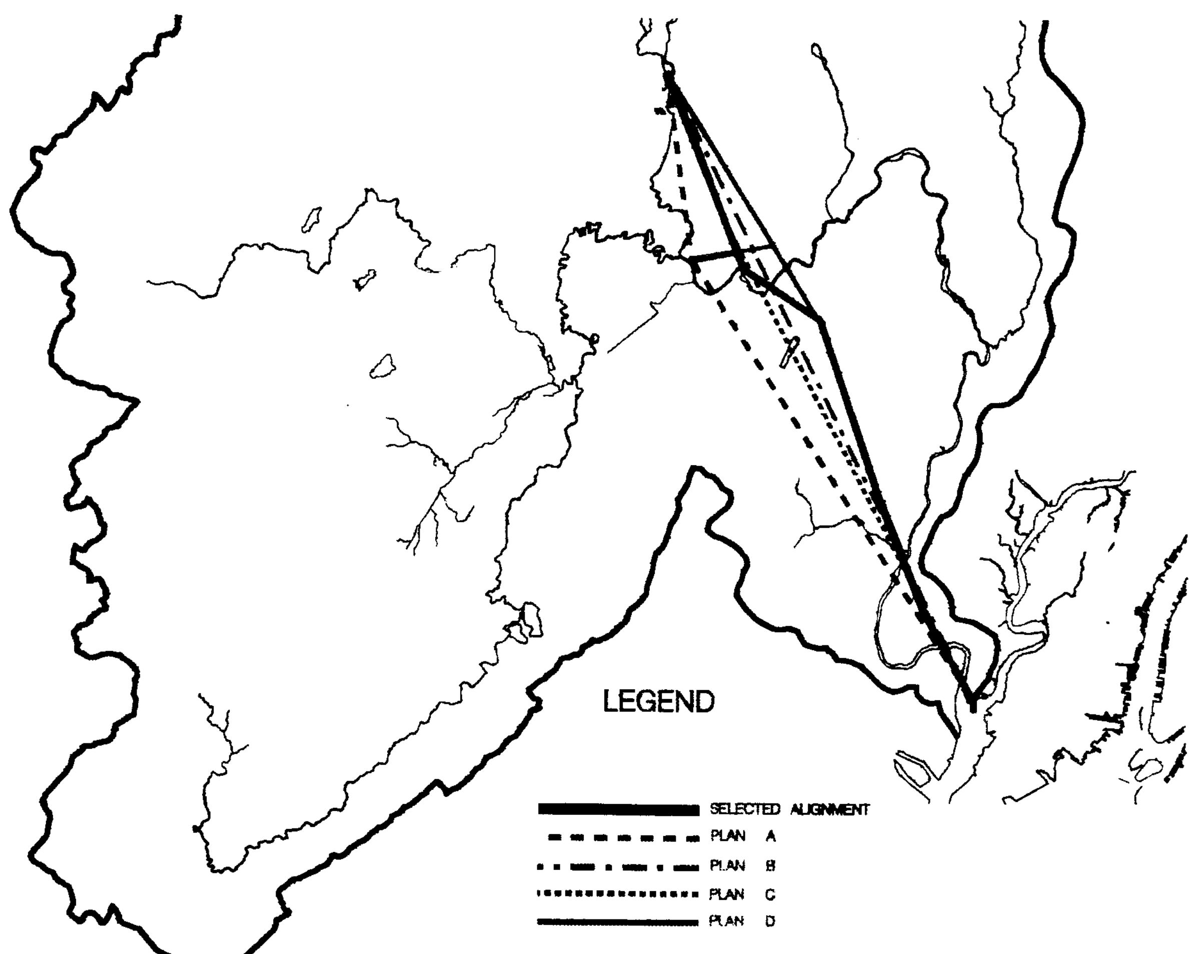
US Army Corps
of Engineers
New York District

Passaic River Flood Protection Project
Preconstruction Engineering and Design

TUNNEL ALIGNMENT SELECTION



MAY 1992

PASSAIC RIVER FLOOD PROTECTION PROJECT

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PASSAIC RIVER FLOOD PROTECTION PROJECT

TUNNEL ALIGNMENT SELECTION

TABLE OF CONTENTS

PASSAIC RIVER FLOOD PROTECTION PROJECT

TUNNEL ALIGNMENT SELECTION

TABLE OF CONTENTS (CONT)

PASSAIC RIVER FLOOD PROTECTION PROJECT

TUNNEL ALIGNMENT SELECTION

TABLE OF CONTENTS (CONT)

LIST OF TABLES

LIST OF FIGURES

PASSAIC RIVER FLOOD PROTECTION PROJECT

TUNNEL ALIGNMENT SELECTION

LIST OF REFERENCES

1. Phase I General Design Memorandum; Flood Protection Feasibility, Main Stem Passaic River - Main Report and Environmental Impact Statement; Vol I; December 1987

2. Phase I General Design Memorandum; Flood Protection Feasibility, Main Stem Passaic River - Supporting Documentation - Hydraulics; Part II; December 1987

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I. Introduction.

The purpose of this paper is to document the review of the selection of a specific tunnel alignment for the authorized Passaic River Flood Protection Project. The Water Resources Development Act of 1990 modified the Corps' Recommended Plan by extending the tunnel to an outlet in Newark Bay. Upon this authorization, several options were reviewed and an alignment concept was formulated. Five of the tunnel alignments considered in this process are described in this document. In presenting this information, the objective was to give decision makers an understanding of the formulation process used to determine tunnel alignment.

The following paper documents the review, logic and assumptions used to determine the specific tunnel alignment upon which future design studies will be based. To date studies are ongoing in the areas of geotechnical design, hydraulic design, economics, cost engineering and real estate. Most importantly for future studies, a detailed economic analysis will be performed which will determine the tunnel diameters by optimizing the level of protection afforded by the Passaic River Flood Protection Project. Other future studies will include tunnel liner analysis, wet versus dry tunnel considerations, tunnel outlet configuration, multi-dimensional numerical models (hydraulic, geotechnical, water quality, environmental, structural, etc.) and the construction of a physical model. These design areas, as well as others, will ultimately impact on the design of the proposed tunnel and its route to Newark Bay.

The discussion that follows first gives a background of the parameters that were significant in the formulation of the Recommended Plan. These parameters were then used to establish the context of the current analysis as applied to the authorized project. Workshaft locations and logistical upgrading of the surrounding infrastructure have long been recognized as a very important factor to construction of the tunnel, the keystone of the Passaic River Flood Protection Project. In fact, due to the heavily urbanized state (industrial, commercial, and residential) of the Passaic Basin, tunnel alignments are significantly influenced by the siting of the workshafts. The necessary removal of material from the tunnel face and an efficient use and/or disposal of up to 10 million cubic yards of excavated rock will require great flexibility in the movement of men, trucks, and heavy equipment for the construction of the tunnel. These requirements significantly reduce the number of potential sites which could ultimately be used as a workshaft site.

The importance in workshaft site selection can not be understated. Contractors bidding on this project should have the greatest freedom possible in terms of work area, staging area and flexibility of transport method. Any limitations placed on the contractor will ultimately show up in the bid price. Therefore, after exhaustive map and field searches for workshaft locations, many of the sites along the tunnel were found to be substantially less than ideal. They are, however, the best sites for the particular alignment and will bear additional costs to the project and inconveniences to the surrounding communities. These conditions are costed where possible but otherwise are qualified in the workshaft description.

Descriptions of the five tunnel alignments follow which discuss potential workshaft sites, geology, hydraulics, operation and maintenance, real estate, and costs. Each alignment has been detailed separately.

At the end of the paper, conclusions and recommendations are presented. Cost estimates, which were developed for each alternative alignment, reflect a detailed analysis which include adjustments for the length of tunnel bored through the harder basalt and softer sandstone/shale formations for each alignment. All alternate alignments increase the length of the more costly basalt tunnelling by making the approach angle of the TBM less perpendicular to the basalt formations. Field investigations of potential workshaft sites were made and the availability of these sites have been reviewed. Based on the information accumulated to date, the selected alignment appears to be the most practicable, feasible and also is the least costly.

II. Background on Tunnelling.

A. Tunnel Technology.

The technology of constructing tunnels with tunnel boring machines (TBM's) has advanced considerably in the past 20 years. Noted advances have been made in both the machines and the systems that support the TBM operation effort. Within the machine itself, significant improvements have been made in the disk cutters and bearings that support the disk cutters. Improved alloys have given longer life to cutters and bearings. This improvement has allowed the manufacture of larger and more durable bearings which allow for larger and longer lasting disk cutters.

Major improvements have also occurred in the main bearing of the TBM cutter head. These improvements allow the cutters to apply greater force against the tunnel face thus making it possible to bore with greater productivity. These advances now make it possible, and more so in the future, to bore a tunnel with a diameter on the order of 45 feet.

Tunnel construction requires an extensive support system to convey the excavated rock (muck) from the working tunnel face back to the workshaft and up to the surface. Until recently, the only available method was the use of muck trains. This method involved the construction of a temporary railroad in the tunnel invert. As the tunnel is excavated, the railroad is used to transport workers and equipment in both directions, while tunnel muck is moved to the workshaft. Recently, conveyers have been developed for muck transport which are a more efficient, continuous transport method and safer than muck trains. Vertical conveyers at the workshaft have also added to this efficiency and with the tunnel conveyor have a combined reliability that exceeds muck trains. Muck removal has often been a constraint on the use of TBM's, often limiting them to an effective utilization rate of about 50%, such as used in the Passaic River cost estimate. However, conveyers used on the Chicago Tunnel and Reservoir Project (TARP) have increased TBM advance rates by 10% through more efficient muck handling.

B. Construction Methods.

Since the excavated tunnel is the work space for a linear construction operation, all support activities and utilities must follow the advancing TBM. Water, electric power, compressed air, and ventilation are all utility lines that must be extended during TBM advancement. However, the most important factor in tunneling is the mucking operation. The longer the excavation reach, the more time it takes to remove the tunnel muck back to the surface. Also, more time is required to move crews and materials to and from the tunnel face. More equipment, including the addition of more railroad cars, etc., is also needed to support the construction at the tunnel face. These factors all add to the cost of construction.

Once the tunnel is excavated, similar concerns would apply to placement of the concrete lining within the tunnel. This would include the costs for additional specialized agitator cars. The optimum length of the tunnel construction "lifeline" is based on several factors which would include but not be limited to:

- o The availability of acceptable workshaft sites
- o Depth and size of the workshaft
- o Labor and utility costs, etc.

For the Passaic River Project, tunnel consultants recommended an optimum lifeline of 4 to 5 miles. Subsequent private sector consultant reviews have confirmed this assumption. This has been the rule in Chicago for its 35 foot diameter tunnels. Certainly the Boston sewer outfall (10 miles) and the English Channel tunnels (six excavated reaches over 10 miles in length, constructed beneath the sea floor) exceed this value, but those projects did not have the option for additional workshafts for less costly operations. On the Passaic project, additional smaller diameter shafts may be constructed along the tunnel alignment, where possible, between the major workshafts. These shafts would be used for emergency access, power drops, concrete drops, more efficient ventilation, and other purposes. These workshafts would make the construction effort more efficient and safer.

When tunneling on a slope, it would be desirable to tunnel upslope. Upslope tunneling would provide the best control for seepage or water inflow. Water entering the tunnel would flow by gravity to the workshaft away from the tunnel face. This inflow would then be collected in a sump and then pumped to the surface. No pumps would be required to protect the TBM from flooding. Although this is the ideal situation, it is not always possible. Examples of downslope tunneling include the Boston sewer outfall and the English Channel tunnels. With these projects, a force main was laid in the tunnel invert and sufficient pumping capacity was supplied. In order to keep up with the advancing TBM, the system would be relocated with the force main extended as necessary. This type of operation would also incur additional energy costs.

The selected alignment of the Passaic tunnel will have one partial reach in which the TBM will bore on a mild downslope. This downslope tunneling results from a lack of a suitable workshaft site over a long tunnel reach. In this case, two TBM's will bore toward each other to split the reach length, one machine going upslope and the other downslope.

Another TBM design consideration would be its removal from the tunnel. Ideally, the TBM would break through to a workshaft or a large access shaft where the machine could be disassembled and lifted to the surface. Because of the lack of a suitable workshaft site for mobilization/demobilization and muck removal, along this same reach, a smaller shaft would be constructed at the mid-point of this reach. A crane or other device could then be positioned to assist in disassembling the head of the TBM. This would allow the machine to be backed out of the tunnel for rehabilitation and possible use on another tunnel segment. The need to disassemble the machine in the tunnel will be a factor in the design of the TBM.

Staging areas for the construction of the tunnel are known as workshafts. At these locations construction labor, materials and equipment move through and down to tunnel level. At the same time, excavated muck removed from the tunnel is either loaded for transport or stockpiled until transport is available. Construction offices could also be located at these sites. It is estimated that 7,000 to 8,000 cubic yards (bulk) of material would be excavated every day from each tunnel heading. Therefore, it is essential that adequately sized sites of at least four to five acres be located near suitable transportation capable of handling this volume of material. Options for muck removal would be:

a. On-Site Storage
b. Barge
c. Railroad
d. Trucks

Total or partial storage at or near the workshaft sites would be ideal, since this method would incur the least cost for transporting the tunnel spoil. Sites located near navigable bodies of water would provide an opportunity of barging the tunnel muck off the site and minimize vehicle movements in the workshaft vicinity. A location near a railroad would provide the possibility for transporting the tunnel muck without imposing a major burden on highways and streets in the immediate area. If the choice of transport is to be trucking, then the area must have highways capable of sustaining heavily loaded trucks at a rate of more than one every minute during the workday. This location must also tolerate around the clock activity and noise for at least 2-3 years. Realistically, it is recognized that relying only on truck transport may greatly limit the logistics of muck removal particularly near residential areas. Consequently, workshaft sites that provide multiple transportation options are highly desirable. Also, it is not desirable to redefine a neighborhood to ideally locate a workshaft. Therefore, workshaft selection criteria would include, but are not be limited to:

- Adequate transport for all construction activities
- Isolation from any residential and commercial areas
- Preferably a disturbed site to minimize any environmental impacts

Disposal cost of excavated materials was based on transport to a location within a 10 mile radius of a workshaft location. While it may be possible to dispose of some muck on-site, such as the shaft site at Montclair State College, it was verified that nearby quarries were interested in the muck based on telephone queries. The Board of Engineers for Rivers and Harbors (now named Washington Level Review Center) in their review of the project also suggested that there may be a market for materials within and beyond the region. During the construction of a project, contractors have been known to be very imaginative in the way they do business including their methods for disposal of excavated materials. Therefore, it is important that the project design give the potential bidders the widest range of options available for disposing the material. In particular, the tunnel availability of more than one option, to transport tunnel muck offsite, could result in lower bid prices.

The cost estimate was based on the use of three tunnel boring machines for all alternatives, and one smaller machine for the spur tunnel. The three machines would be purchased by the contractors and manufactured during the first two years of construction. During this time, workshafts and tail tunnels would be constructed to receive the TBM's so that construction could proceed as the TBM's arrive on site. Construction would start within the lower leg of the main tunnel at the most downstream workshaft. As construction proceeded and the first machine completed its tunnel segment, it could be removed from the tunnel, overhauled, and placed in service on the upper leg of the tunnel. When the machines were no longer needed, they would be sold for salvage value.

C. Previous Formulation.

The feasibility report on the Main Stem Passaic River Flood Protection Project addressed many formulation concerns detailing the alignment. The resolution of these concerns has application to the selection of a tunnel alignment for the authorized plan as well. Some of the major concerns are briefly summarized in the following text based on documentation in Appendix C - Plan Formulation of the feasibility report.

Hydrologic and hydraulic studies determined the most suitable locations for the tunnel inlets and those results hold true for the authorized plan. Alternative projects with combined channels and shorter tunnel lengths were found to be more costly. It was also determined that, although a tunnel profile constructed at the hydraulic gradient was desirable, geologic, constructability, and cost concerns dictated that it was necessary to lower the tunnel profile well below sea level. This would minimize surface disruption, environmental impacts and provide competent bedrock cover above the crown of the tunnel. With the tunnel lowered, the most economical construction techniques can be used.

Since suitable workshaft sites were a critical factor in the selection of a tunnel alignment, and since the geotechnical information available at this time is incomplete, a choice of the most favorable alignment from a geotechnical standpoint could not be made. While it is possible to weigh the advantages and disadvantages of a particular alignment based on the surficial geology, it really depends on the subsurface conditions as to which tunnel alignment will produce the lowest geotechnical problems. In this regard, it may be said that since the ongoing subsurface investigation has concentrated exclusively on the Selected Alignment, there is now a greater degree of certainty associated with the Selected Alignment rather than any of the alternatives. This fact now puts the other possible alignments at a disadvantage when geotechnical parameters are figured into the analysis on which tunnel alignment is the most suitable.

To the extent that geologic considerations based on surficial information could be utilized in the development of the cost estimate, difficulties of a minor nature are expected in several narrow fault zones which cross all of the tunnel routes due to their northeast/southwest trend. The selected route crosses the faults at a near perpendicular angle thus minimizing the tunnel length in these zones. Emphasis was focused on dips in bedrock in the buried valleys in Wayne Township. A buried valley in this area trends in the same northeast/southwest direction, making it difficult to avoid unless the alignment is located a mile or more to the east. However, moving the alignment this far east would result in workshaft locations in a mountainous residential area with no major highway or railroad for transport of excavated muck, materials and equipment. Although the buried valley dips within 40 feet of the tunnel crown, review by private sector tunnel consultants viewed this as a constructable reach.

Another known geologic feature is a buried valley or glacial plunge pool dipping to sea level as shown on the State of New Jersey Route 202 borings in the Mountainview area of Wayne. This feature is located on a line drawn between the Pompton and Passaic inlets and was one of the reasons for utilizing a spur tunnel to the main tunnel rather than a single main tunnel from the Pompton inlet south to the Passaic inlet location. Should additional buried valleys impacting on the tunnel profile subsequently be discovered in the course of the geotechnical investigation, it is planned to address the problem by redesigning the tunnel or lowering the tunnel invert.

The most significant concern for all alignments was the selection of workshaft sites. These sites serve as staging areas for all construction activities, the most critical being the handling and removal of the tunnel muck. Critical requirements for these sites included the availability of about 5 acres or more of land, access by major highway and another mode of transport such as rail or barge, and isolation from surrounding residential and commercial activities. Another requirement beneficial to a site would be access to a nearby disposal area for the tunnel muck. Smaller access shafts are required at other locations along the alignment for other purposes. Some shafts would also serve a useful function to the operation and maintenance of the tunnel after the construction period. Finding locations suitable for these shafts in the highly urbanized Passaic River basin involved both the study of maps, aerial photography, land use, and field investigations by District staff and tunnel consultants, and contact with local officials.

Key critical sites include both inlets and the outlet location all of which are and will likely remain available until purchased by the state. The intermediate workshaft locations were selected based on standard criteria although it was difficult to site completely satisfactory locations for all plans. These selections were important in defining the construction procedures and schedules.

In addition to the above, the Montclair Workshaft #2 is also considered a key critical site due to:

a. central location,
b. planned heavy use for dual heading muck removal and,
c. satisfaction of criteria.

This location is also one reason for the bend or angle point in the tunnel alignment. This relatively isolated site (former rock quarry) is situated away from residential and commercial activities and located adjacent to distant parking lots for Montclair State College. The required real estate is available in an already disturbed state. The site is accessible to major highways (Routes 3, 46 and 80) and rail transport. It is also near to another large abandoned quarry and a large active quarry, both of which could be receivers of tunnel muck. It is noted that the abandoned quarry may be developed in the future for commercial purposes. Montclair College is already owned by the state and will be available for several years. This site can accommodate a permanent installation for post construction operation and maintenance purposes. A minor drawback to the site is its elevation which will require a deep shaft to the tunnel invert. This deep shaft will incur greater energy costs associated with bringing tunnel muck to the surface. This cost is a minor consideration when compared to other potential sites which can not satisfy the critical criteria.

III. Selected Tunnel Alignment.

During the feasibility study (Phase I GDM Report), numerous inlet and tunnel alignment schemes were evaluated during the design of the Passaic River Flood Protection Project. After significant hydrologic study effort, the concept of a dual inlet tunnel was devised, studied and ultimately considered as the most viable solution capable of providing flood relief to the heavily urbanized Central Basin and Lower Valley areas of the Passaic Basin. Tunnel alignments presented here include inlets at both the Pompton and Passaic sites as described below (see Physical Features). Phase I GDM tunnel alternative alignments would have discharged tunnel outflow at the confluence of the Third and Passaic Rivers (Recommended Plan, Phase I GDM Report), at the confluence of the Second and Passaic Rivers, or directly into Newark Bay.

The current outlet location within Newark Bay, 1,400 feet south of Kearny Point, is tentative pending further studies. This site was selected in place of a closer site in the City of Newark because the Newark shoreline is almost completely developed for waterfront uses. Also, the close proximity of the Passaic navigation channel would influence outlet site selection. Therefore, locating the outlet along this bank was not considered practical. On the left bank along the

Kearny shoreline, the same was true. Therefore, the most practical outlet location was in the vicinity of Kearny Point, where no navigation facilities exists along the shoreline.

From a hydraulic point of view, this places the outlet near the junction of the Hackensack and Passaic River navigation channels which would provide the maximum channel capacity and thus minimize the movement of bottom sediment. For cost estimating purposes, the outlet was assumed to be offshore near the navigation channel because of the potential environmental concerns to avoid disrupting the bay bottom near the shore. Detailed design will be determined during the precise location of the outlet.

Figure F-1 provides an overview map showing the various alignments considered in this analysis.

A. Selected Alignment.

1. Physical Features. The proposed physical features of the plan as shown on Figure F-2, will be briefly described here. As described above, the selected alignment has two inlets where floodwaters are collected and conveyed by underground tunnel to an outlet located off Kearny Point.

The key to this and any other alternate alignment was the optimum location of workshafts. These workshaft locations became the critical and overiding element in determining the subsequent direction of the tunnel. The connections between these identified workshafts determined the final alignment. Therefore, tunnel alignments were a function of the positions of the proposed workshafts.

In formulating this alignment, it was decided that the workshaft locations to the north of Workshaft #2 would remain the same. Therefore, the unknowns were in general, everything south of Workshaft #2. The initial assessment looked at a straight run, the shortest run and least cost, from Workshaft #2 to the Newark Bay Outlet. During the formulation review process, all workshaft site possibilities located within a reasonable distance to the east and west of this alternate were considered. During this review process, due to the lack of significant alternate workshaft sites, the concept of the "hook hole" at Workshaft #2A was considered and ultimately selected for use as part of the final tunnel alignment.

For more information the reader is referred to the Phase I GDM, Flood Protection Feasibility -Main Stem Passaic River, Main Report and Supporting Documentation, Part II, Hydraulics, December 1987. The following descriptions were generally taken from the noted report.

a. Pompton Inlet and Associated Features

(1) Pequannock Weir. The Pequannock Weir would consist of placing 2 bascule gates, each 15 ft. high by 85 ft. long, within a portion of the existing earthen dike now part of the old Morris Canal feeder dam. This structure would be operated in conjunction with the Pompton Flow Restrictor and improved Pequannock Channel. The gates would normally be maintained in the up (closed) position. However, during flood events, the gates would be lowered to permit flow to enter the improved Pequannock Channel and approach the Pompton Inlet with superior hydraulic conditions.

(2) Approach Channel Modifications. Modifications are proposed along Pequannock, Wanaque, Ramapo and Pompton Rivers. These improvements would reduce flood stages by increasing channel conveyance, lower stages in areas that require levees (thereby reducing levee heights) and redirect the flood flows more efficiently to the Pompton Inlet. Channel improvement lengths vary from 700 ft. to 13,500 ft., maximum cuts up to 10.9 ft., and proposed bottom widths vary from 60 ft. to 129 ft.

(3). Pompton River Flow Restrictor. The flow restrictor would consist of 1,470 feet of earthen embankment and 5 box culverts (30 ft. in width) which are controlled by roller gates. The purpose of the flow restrictor would be to control flows past the Pompton Inlet and therefore limit downstream flooding. Operating the flow restrictor gates in combination with the spillway diversion gates would allow flood waters to be diverted into the main tunnel and bypass suspectible flood damage areas of the Passaic Basin. Under normal conditions, flows continue downstream on the Pompton River and no tunnel diversion occurs. During flood conditions all but 500 cfs would be diverted into the tunnel. Bypass flows are required to be maintained during flood events for in-stream needs within the Pompton River. For floods in excess of the tunnel capacity, the river flow restrictor gates would be opened, thus allowing additional flow to bypass the tunnel inlet and move downstream along the Pompton and Passaic Rivers.

(4). Pompton Diversion Spillway The diversion spillway would consist of 5 bascule gates each 5.5 ft. high by 75 ft. long. The gates are maintained in the up position (closed) with normal Pompton River flows remaining within the river. During flood conditions the gates are lowered and flood waters are allowed to enter into the access basin and eventually into the morning glory spillway and main tunnel.

(5). Pompton Inlet. The inlet consists of a morning glory spillway centered in a 160 ft. minimum radius access basin. The spillway crest of the morning glory would have a maximum spillway diameter of 84 feet and would be elevated 8 feet above the floor of the access basin for safety purposes. The morning glory would then transition down to the required 40+ foot diameter main tunnel.

(6). Main Tunnel. The main tunnel was originally determined in the Phase I GDM to have a length of 71,000 feet, an approximate diameter of 39 feet and discharge at the confluence of the Third and Passaic Rivers. However, the project was modified by Congress and is now authorized to discharge directly into Newark Bay, would have an approximate length of 106,000 feet and a diameter of 40+ feet. The design tailwater was elevation 15.4 NGVD in the Phase I GDM, however with the tunnel now discharging into Newark Bay the design tailwater would be lowered to approximately elevation 5.50 NGVD.

b. Two Bridges (Passaic River) Inlet and Associated Features.

(1). Great Piece Meadows Weir. The weir would consist of placing a bascule gate 13.75 ft. high by 100 ft. wide across the Passaic River approximately 2,500 ft. upstream of the proposed Two Bridges Inlet. In combination with the bascule gate, two small earthen embankments (average height of 3 feet and a total length of 750 ft.) would be tied into high ground to prevent flanking of the weir during the 1 year wetland inundation. Under normal conditions the gate would be maintained in the down (open) position thus allowing Passaic River flows to continue downstream. This structure would only be operated during the receding portions of a flood, in an attempt to retain the 1 year flood stage within the Great Piece Meadows wetland area. The weir would also be designed to operate as a grade control structure and prevent headcutting from occurring on the Passaic River.

(2). Approach Channel Modifications. Approach channel modifications are proposed in the vicinity of the confluence of the Passaic and Pompton Rivers. These improvements are proposed to reduce flood stages by increasing channel conveyance, lower stages in areas that require Central Basin levees (thereby reducing levee heights) and to direct the flood flows more efficiently to the Two Bridges Inlet. Channel improvement lengths vary from 1,800 ft. to 4,600 ft., maximum cuts up to 6.2 ft., and proposed bottom widths vary from 150 ft. to 170 ft.

(3). Two Bridges Diversion Spillway. The diversion spillway would consist of 4 bascule gates each 14.8 ft. high by 100 ft. long. The gates would be maintained in the up (closed) position with normal Passaic River flows remaining in the river. During high flow conditions the gates would be lowered and flood waters allowed to enter the access basin and eventually into the spur tunnel.

(4). Two Bridges Inlet. The inlet consists of a morning glory spillway centered in a 150 foot minimum radius access basin. The spillway crest of the morning glory would have a maximum spillway diameter of 56 feet and would be elevated 7 ft. above the floor of the access basin for safety purposes. The morning glory would then transition down into the spur tunnel.

(5). Spur Tunnel. The spur tunnel was determined in the Phase I GDM to have a length of 6,500 feet, approximate diameter of 22 feet and discharge into an underground connection with the main tunnel. A smooth transition from the spur tunnel into the main tunnel will be designed to minimize the impact of joining flows within the two diversion tunnels.

c. Tunnel Outlet. The outlet of the main diversion tunnel will be located approximately 1,400 ft. off Kearny Point. At this time, no detailed outlet configuration has been designed however, preliminary conceptual designs have been performed. Based on the preliminary designs, it would be desirable to design the outlet to maintain a positive hydraulic head from Newark Bay waters on the flows emerging from the structure, minimize lateral velocities, prevent scouring in the vicinity of the structure and disperse the tunnel discharge in as large an area as possible thereby minimizing impacts to existing river and tidal currents and sediment transport conditions. A gated structure would also be considered for design of the main tunnel outlet in Newark Bay. Gates on the outlet would allow the tunnel to be maintained dry prohibiting waters from entering the tunnel, as is presently planned.

d. Workshaft #3. The purpose of this workshaft is for TBM removal and emergency ingress and egress.

This workshaft is located in Wayne, Passaic County, New Jersey in an area known as Preakness Valley Park. It is situated directly on the selected tunnel alignment and lies 23,000 linear feet south of the Pompton River Inlet Site. The availability and utility of this site has been verified by field investigations and subsurface testing. Most significantly, this particular workshaft will not be used for removal of muck. Its sole purpose is for TBM removal and emergency purposes. Therefore the selection criteria were much less stringent for this workshaft than the others. Requirements at this site included the need for an open area approximately 2 acres in size. This site would be used as an area for the mobilization/demobilization of the heavy equipment needed to remove two TBM's from the tunnel arriving from both directions. It should be noted that the muck removal for these reaches of tunnel is anticipated to take place at the Pompton River Inlet which would serve as a workshaft until completion of the tunnel and the Mountclair Workshaft #2.

e. Workshaft #2. The purpose of this workshaft is for muck removal which will be received from dual headings simultaneously.

This key workshaft is the most important workshaft and is critical to the viability of the entire alignment. It is located in Little Falls, Passaic County, New Jersey in a low-lying depression area on the northerly border of the campus of Montclair State College. The ideal location of this workshaft served as the basis for the route of the selected alignment and therefore it's location served as the reason for the bend or angle point in the route. The availability and utility of this workshaft site has been verified by field investigations and subsurface testing. This workshaft would be used for muck handling and is accessible to major highways (Routes 3, 46 and 80) and rail transport. The area in and around the workshaft appears large enough to not only handle the daily output of muck but also store a minimum of 3 to 5 days worth of TBM output. Temporary storage of muck would avoid any slow down in tunnel excavation due to any potential off-site muck removal problems, such as weather, traffic slowdowns etc. For the workshaft and storage area, four acres were used to determine the project cost. Subsequent discussions between this office and the officials of Montclair State College have revealed that as part of their overall master plan for re-grading the campus, the college would welcome good clean fill. Therefore, a portion of the excavated material could be disposed of on-site.

f. Workshaft #2A. The purpose of this workshaft is to serve as an access point, allowing a hook to be lowered by construction crane down to the TBM in the tunnel so the cutterhead can be disengaged from the front of the TBM.

This workshaft is located in Belleville, Essex County, New Jersey in the northeast corner of the Hendricks Field County Golf Course. It is situated directly on the selected tunnel alignment and lies 25,000 linear feet south of Workshaft #2. The utility of this site has been confirmed through numerous field visits. This workshaft has become known as the "hook-hole" workshaft. The reason for this is due to the fact that no muck removal or TBM removal will take place at this location. The workshaft would serve as a temporary access point for a construction crane to lower a hook into the tunnel. With the use of this hook, crews in the tunnel would then disengage the cutter head from the TBM thus allowing the entire machine to be backed out of the tunnel. The size of the workshaft has been estimated to be 10 ft. in diameter with a surface area of 2.5 acres. This should cause no major inconvenience to the Golf Course since this workshaft would be sited away from active golf play.

g. Workshaft #2B. The purpose of this workshaft is for removal of tunnel muck and also for an alternate means of ingress and egress for the tunnel crews.

This workshaft is located in Kearny, Hudson County, New Jersey in an industrial area of town on Bergen Avenue just off Schuyler Avenue. It is situated directly on the selected tunnel alignment and lies 17,000 linear feet south of Workshaft #2A. Past field investigations have confirmed the utility and feasibility of this workshaft site. Recent field investigations have revealed that this area is now a parking area for trucks and waste containers. While this is not a major impediment to the utilization of this site, it would cause for some delays due to future real estate investigations, acquisitions etc. A recent field trip also revealed an alternate site, which in fact may prove to be more advantageous than the original location. For this reason it was decided that Workshaft #2B be incorporated into each alternative alignment plan. This site is at the south end of Bergen Avenue on the north side of the Erie Lackawanna railroad tracks. This workshaft site would be used for muck removal and tunnel crew access. The workshaft could be located here with the tunnel muck brought to the surface with a vertical conveyor and then dropped directly into a waiting railroad car for transport to the Passaic or Hackensack Rivers for placement on barges or to a disposal or commercial/retail site. This would make for a very efficient operation. The possibility also exists that some of the tunnel muck can be, depending upon local ordinances, placed at one or more of the landfills that are in the immediate area. As a third option, muck material could be stored/delivered for use as part of the embankment material for the hurricane levees.

h. Workshaft #2C. The purpose of this workshaft would be for muck removal and tunnel crew ingress and egress. It would also provide access for the tunnel discharge lines and pump stations that would pump the tunnel dry after each flood event.

This workshaft is located in Kearny, Hudson County, New Jersey, in an industrial area near a sewage treatment plant. The sewage treatment plant itself contains a relatively open area where the workshaft could be located. This proposed workshaft is situated near the end of, and is common to, all five alignments. It lies 16,000 linear south of Workshaft #2B. A 1,200 linear foot railroad spur could be constructed to a nearby active line in order to transport the muck material as it is removed. However, it has been assumed that most, if not all of the material from this workshaft would be barged to a disposal site. It could also be stored/delivered for use as the embankment material for the hurricane levees along the lower Passaic River.

2. Geotechnical Design. There have been limited geotechnical investigations completed to date. However, all 5 alignments would appear to have similar geotechnical concerns.

a. Tunnel Geology. The alignment of the Passaic River Basin Tunnel cuts across the strike of the Newark Basin (Figures G-1 & G-2). The tunnel outlet, in the vicinity of Kearny Point on Newark Bay, is the lowest point in the geologic sequence. Proceeding up-section from the outlet, the tunnel will traverse the Passaic Formation, the Orange Mountain Basalt, the Feltville Formation, the Preakness Mountain Basalt, the Towaco Formation, the Hook Mountain Basalt and finally the Boonton Formation. Overall, the main tunnel will be excavated through approximately 89,500 linear feet of sedimentary rock consisting primarily of fine sandstone, siltstone, and shale and about 16,500 linear feet of basalt. The spur tunnel will encounter the Preakness Mountain basalt and the Towaco Formation.

During the early feasibility studies, unconfined compressive tests were conducted on the rock materials that exist along the tunnel alignment. The test data indicates a range from 5,450 psi to 34,200 psi with an average 14,010 psi for the four sedimentary formations. The three basalt formations range from 7,720 psi to 48,580 psi with an average 23,370 psi.

Overall, the rock quality at the tunnel elevation can be considered good to excellent for tunnelling. It is relatively massive and only moderately jointed with many of the joints healed. However, it should be noted that considerably more investigations and testing are planned to confirm these assumptions, during subsequent design activities.

b. Structural Geology. The Newark Basin formations strike in a northeast-southwest direction and dip between 7 and 15 degrees to the northwest. The prominent structural features relative to the tunnel design and construction are a series of inactive faults in the vicinity of the Watchung Mountains. The faults generally strike in a northeast-southwest direction and dip toward the east at relatively high angles. Five faults have been observed or inferred thus far.

Early investigations have provided information on the condition of the faults that the tunnel will be constructed through. The actual faults are relatively narrow ranging from about 6 inches to 4 feet. They contain varying degrees of clay gouge and breccia. Extending outward from the faults are zones that exhibit a relatively high degree of jointing and brecciation. The joints and breccia interstices in these zones are healed with calcite or gypsum to the extent that the rock cored relatively solid and unbroken. These zones appear to extend from as little as 5 feet to as much as 50 feet to either side of the fault. It can be assumed that poorer quality rock will be encountered for some distance to either side of the faults. It is not yet known how much of the tunnel will be excavated through fault zones. It is presently estimated at up to 200 feet. The tunnel runs nearly perpendicular to the faults which will minimize the length of excavation through this less suitable material. Evaluation of these fault zones is a primary objective of future investigations.

c. Buried Valleys. Buried valleys or bedrock lows are known to exist in the project area as shown on Figure G-3. Significant bedrock lows that will impact the tunnel depth appear to be located only in the sedimentary formations. The most significant of these is located in the Kearny area where the top of rock dips to nearly 300 feet below sea level. There is strong evidence of another significant bedrock low near the Mountainview area of Wayne Township where the top of rock dips to nearly sea level. This feature is often referred to as the "plunge pool". Identification and defining limits of bedrock lows is one of the key objectives of the exploration program.

d. Additional information. For more information on project geology the reader is referred to the Phase I GDM, Flood Protection Feasibility - Main Stem Passaic River, Supporting Documentation, Part III, Foundations, December, 1987.

e. Summary. As stated above, any of the proposed alignments appear feasible from a geotechnical/geological viewpoint. All of the alignments will encounter the same geologic environment. The same rock formations will be encountered regardless of the chosen alignment. Given the fixed location of the outlet, the buried valley in Kearny will impact all alignments equally. The extent of faulting is not yet fully known, but is likely to follow a similar trend along the Watchung Mountains. It is quite probable that any of the considered alignments will encounter the same degree of faulting in the Watchung Mountain area.

Consideration should be give to the orientation of geologic structures, such as faults and the contacts between different rock formations. It is desirable to have the tunnel intersect these features as near to perpendicular as possible. For this reason, it is beneficial (from a construction viewpoint) to maintain the Selected Alignment through the Little Falls area, since several northeast-southwest trending faults and contacts are known to exist in this area. See Figure G-3.

3. Hydraulic Design. Hydraulic calculations to date indicate that head losses through the main tunnel are dominated by the frictional loss component (approximately 90%). This is a direct result of the long tunnel length, currently estimated to be approximately 20.1 miles. If the main tunnel could be significantly reduced in length, other loss components such as entrance, transition, vertical and horizontal bends, junction with spur tunnel, and exit coefficients would become more influential in determining the required tunnel size. However, since the authorization dictates that the diversion tunnel discharge within Newark Bay, the main tunnel lengths as given in Table H1 are not significantly different between the Selected Alignment and Plans A, B, C and D. As such, the frictional head loss component would still be the dominant factor in the main tunnel computations. Reducing the number of horizontal and vertical bends would be beneficial hydraulically, however their impacts are rather insignificant when evaluated in context of the overall analysis. Table H1 also provides a comparison of the hydraulic elements which would vary as a result of the different alignments to Newark Bay. These elements would be used in calculating the design discharge for a given tunnel diameter.

For the spur tunnel, tunnel lengths vary significantly for the various alignments (see Table H1). Since the spur tunnel is significantly shorter in length then the main tunnel, form losses would be a significant part of the overall head loss. For the plans discussed below, form losses can exceed 40% of the total head loss calculated.

Main tunnel. A preliminary analysis was computed to determine the impact of the various tunnel alignments on the tunnel diameter. The Pompton Inlet was assumed to be submerged. The frictional length used in this analysis was 106,565 ft. The length included the vertical drop at the Pompton Inlet and vertical rise at the Newark Bay outlet. Loss coefficients were determined with a roughness coefficient k=0.002 as recommended in EM 1110-2-1602, page 2-10. With this k value, the resistance factor f, was found to be approximately 0.0105 and varies with both velocity and tunnel diameter.

With the above f=0.0105, Manning's "n" value was determined to be 0.014. However, it should be noted that a project of similar size, shape and construction method had a measured k=0.00018. Converting this k value to a Manning's frictional value results with "n" = 0.012. For purposes of analysis, the more conservative f = 0.0105 ("n" = 0.014) is used in this paper to develop a relative change in diameter for each alignment.

Spur tunnel. As was the case for the main tunnel, the spur tunnel inlet was assumed to be submerged. The frictional length used in this analysis was 6,630 ft. The length included the 130 ft vertical drop at the Two bridges Inlet. Frictional losses were again determined with a roughness coefficient k=0.002. For this analysis it was assumed that the upper leg of the main tunnel (from Pompton Inlet to confluence with the spur tunnel) was not yet constructed. The Phase I GDM analysis indicated that the capacity of the spur tunnel was dictated by the need to bypass larger flows at Two Bridges Inlet prior to completion of the upper leg of the main tunnel. The resistance factor f, was found to be approximately 0.0118 and varies with both velocity and tunnel diameter.

4. Cost Engineering. The costs used in this analysis are at the October 1989 price level.

a. Geological Cost Analysis. As shown on Figure G-3, the Selected Alignment passes through several distinct rock types. For the purpose of this analysis, rock types were divided into two basic formations - sedimentary and basalt. The Selected Plan would be excavated through approximately 89,500 linear feet of sedimentary rock and 16,500 linear feet of basalt, with the basalt formation more difficult to bore. Refer to Table C1 for a comparison of the estimated linear feet of basalt that each alternate alignment will penetrate. A comparison of boring time between the sedimentary and basalt formations show a significant increase in time and therefore cost for basalt boring.

The rate of TBM advance is 50 feet per day for basalt and 100 feet per day for sedimentary rock. These rates translate into labor and equipment costs. There are also material and support costs such as replacement of cutter heads and temporary structural support which will vary in cost between rock types. The costs due to advance rate differences, however, far outweigh these cost differences.

Alignments that increase the length of tunnelling through basalt would lengthen the construction schedule. This would impact job scheduling, fiscal year funding and most significantly the interest during construction. With an extended schedule, the interest during construction and total annual cost would increase while the benefit to cost ratio would be reduced. Presently, the interest during construction for the main tunnel of the Selected Plan has been estimated at approximately 29% of the first cost. The spur tunnel has been estimated at 11%.

For the Selected Alignment, the period of excavation time noted below will be the basis for comparison with the other alternatives. Based on the above geologic information, the excavation duration for the main tunnel of the Selected Plan is estimated at:

89,500 Ft Sedimentary Rock	@ 100 ft per day	=	895 days
16,500 Ft Basalt Rock	@ 50 ft per day	=	330 days
	Total	=	1,225 days

Approximate total excavation cost:

$550,000,000 for 1,225 days = $449,000 per day

b. Total Construction Costs. The costs for this plan will be used as the basis for comparison with the alternative alignments. The tunnel for the Selected Alignment on a per foot basis would be computed as follows:

Main Tunnel:

Inlets, Outlet & Shafts	@ 23.7 mo =	498 days =	$ 58,650,000
Excavation ($449,000 per day)	@ 58.3 mo =	1,225 days =	$550,000,000
Concrete ($564,000 per day)	@ 22.0 mo =	461 days =	$260,000,000
	104.0 mo	2,184 days	$868,650,000

Tunnel Segment	Length	Costs	Per Foot Costs
Main Tunnel	106,000 ft	$ 868,650,000	$ 8,200
Spur Tunnel	6,500 ft	$ 44,513,000	$ 6,850
Real Estate		$ 4,422,000	

Selected Alignment:

Total Tunnel Cost = $ 917,585,000

c. Additional Information. For more information on project cost estimates the reader is referred to the Phase I GDM, Flood Protection Feasibility - Main Stem Passaic River, Supporting Documentation, Part IV, Cost Estimates, December, 1987. Additional documentation can be found in the January 1991 M-CACES cost estimate.

5. Real Estate. Real estate costs for this Selected Alignment will be used as the example against which the other plans will be evaluated. For the Selected Alignment, Real Estate costs are as follows:

Surface Easements:		
Workshafts (6), Inlets (2), Outlets (1)		$ 3,543,000
Sub-Surface Easements:		
Tunnel	112,500 lf @ $6.24/lf	$ 702,000
Administrative Costs:		
Planning, Surveys, Appraisals and Admin.	112,500 lf @ $1.57/lf	$ 177,000
	Total cost =	$ 4,422,000

6. Operation and Maintenance. For this analysis, the tunnel was assumed to remain dry between flood events. Therefore, in order to accomplish this (excluding infiltration), it would be desirable to construct as much of the tunnel above sea level as possible. However, from a geological standpoint, constructing the entire tunnel above sea level cannot be accomplished since tunnel construction procedures recommend a minimum rock cover of at least one tunnel diameter, above the crown of the tunnel. In this case, at least 40 feet of rock would need to be maintained above the tunnel crown.

Based on present geologic information, the top of rock in the lower portion (towards Newark Bay) dips well below sea level. Consequently, 40% of the tunnel length would be below sea level.

Therefore, in order to maintain a dry tunnel, pumping would be required. After each flood event the tunnel would be pumped dry. During low flow conditions, ground water infiltration and seepage at the outlet gates would need to be removed by pumping. Visual inspections of the tunnel would also necessitate an evacuated tunnel. To maintain the necessary hydraulic capacity, the tunnel would need to be kept clean and free from sediment and debris accumulation by a periodic maintenance program.

Annual O & M Costs

The following are the annual maintenance costs, along with the yearly cost of electricity. Salaried personnel costs necessary for the removal of muck to clean out and maintain the tunnel, inlets, workshafts and outlet were developed. The costs for any miscellaneous expenses (materials, supplies, etc.) were also estimated:

Item	Annual Cost
Pump Out:	
Advanced replacement of pump motors, controls and installation	
Yearly power costs	$ 307,000
Silt Removal:	
Advanced replacement of headframe, and other related equipment	
Muck removal	$ 120,000
Salaried Personnel:	$ 230,000
Clean Out & Maintain:	
Tunnel, inlets, workshafts, etc.	$ 135,000
Miscellaneous:	

Materials, supplies, etc.	$ 33,000
Total Annual O & M Cost	$ 825,000

IV. Alternate Tunnel Alignments.

During the formulation process, a number of tunnel routes were considered for the extension of the tunnel to Newark Bay. As shown on Figure F-1, all alignments used in this analysis included the dual inlet concept with the tunnel outlet diverting flow directly into the bay. All tunnel routes were evaluated with special consideration given to the workshaft siting, since these features are critical to the feasibility of each tunnel alternative. Site selection was based on investigations consisting of review of USGS quadrangle sheets, review of the most recent aerial photography and field investigations at potential workshaft sites that passed initial screening. All potential workshaft sites were evaluated for available land, the number of transportation options possible, surrounding environment, the existence of a disturbed or undisturbed location, existing roadway and railroads, and the potential for surface logistical upgrading. During this process workshaft locations slightly to the east and west of each alignment were also considered. However, no locations removed from the tunnel alignment proved to be a substantial improvement and all routes retained workshafts directly over the tunnel alignment. The following paragraphs will briefly describe the logic and thought process used in developing each alternative alignment with a more detailed description following in this section of the report.

Alignment A, Figure F-3. This plan would eliminate the cost of and the need for the spur tunnel. By directly linking the Pompton River Inlet to the Two Bridges Inlet, with the underground diversion tunnel, no spur tunnel would be required and its associated cost would be eliminated. Downstream of the Two bridges Inlet the tunnel would then proceed directly to Workshaft #2B, located on the selected alignment, and then on to Newark Bay. The total main tunnel length would be 106,150 feet with no spur tunnel required. The plan also results in a longer tunnel boring length through the harder basalt formation then in the Selected Alignment.

Alignment B, Figure F-4. This alignment was formulated to develop the minimum main tunnel length by directly linking the Pompton Inlet to workshaft #2B. This plan yields the shortest main tunnel length at 104,200 feet, however the spur tunnel length increases to 9,000 feet. The plan also results in a longer tunnel boring length through the harder basalt formation than in the Selected Alignment.

Alignment C, Figure F-5. This alignment would eliminate the need for the bend in the Selected Alignment that directs the tunnel to the Montclair workshaft (see Figure F-2). By eliminating this bend, the main tunnel route would decrease in length, reduce in cost and eliminate the two (2) horizontal curves in the Selected Alignment. The main tunnel length is reduced to 104,400 feet while the spur tunnel length increases to 7,000 feet. This plan also increases the boring length in the harder basalt formation and therefore, adds to the construction duration of the main tunnel.

Alignment D, Figure F-6. This plan was developed to eliminate the northern most horizontal bend in the selected alignment, by directly linking the Pompton Inlet with the Montclair Workshaft #2. Downstream of this workshaft the tunnel route follows the Selected Alignment and all workshafts are identical. The main tunnel length is reduced to 104,900 feet while the spur tunnel increases to 11,200 feet. This plan also increases the boring length in the harder basalt formation and therefore, adds to the construction duration of the main tunnel.

Described below are the details and results of the investigations for each alternate alignment.

A. Plan A

1. Physical Features. The basic features of Plan A, as shown on Figure F-3, consist of a straight tunnel run from the Pompton Inlet 27,750 ft south to the Two Bridges Inlet; then directly to Workshaft #2B a distance of 61,000 ft. The overall distance is 106,150 ft making the main tunnel 150 ft longer than the Selected Alignment.

The advantages of this plan would be:

- o The elimination of the Spur Tunnel since the main tunnel would pass adjacent to the Two Bridges Inlet location
- o Elimination of hydraulic bends in the tunnel

The disadvantages of this plan would be:

- o Lack of suitable workshaft locations
- o Longer construction duration therefore more interest during construction (IDC) than the Selected Alignment
- o Strong likelihood of increased costs due to surface delays, slowdowns and/or logistical problems
- o Tunnel will be constructed through the "plunge pool" area
- o TBM will have to bore through a longer length of basalt rock

- o Additional construction costs associated with the large underground chamber at the Two Bridges Inlet
- o Possible hydraulic problems at the Two Bridges Inlet with the flow cascading down on the main tunnel flow
- o Higher O & M cost due to the additional pumping station at Workshaft #A1
- o Additional silt and sediment removal due to the longer length of tunnel below sea level

a. Workshaft #A1 The purpose of this workshaft is for TBM removal and emergency ingress and egress.

A field verification was made of this proposed workshaft to evaluate its viability. The site is located in Wayne, Passaic County, New Jersey in an area directly between the Erie Lackawanna Railroad to the west and Route 23 to the east. It would be situated directly on the tunnel alignment and would lie 18,000 feet south of the Pompton River Inlet site.

The surrounding area is both residential and/or commercial. The railroad is active and shows signs of being recently maintained. There also appears to be sufficient area for a workshaft, since the site is not heavily developed. This area is relatively isolated and most environmental concerns (noise, dust, traffic etc.) would be kept to a minimum.

Muck removal could be performed by either railroad cars or trucks. On-site storage of tunnel muck beyond a 3 to 5 day period would not be feasible. In order to move the tunnel muck by truck (the nearest major highway is Route 23), a 1,200 foot connecting road would be constructed. To utilize the railroad, a 500 linear foot railroad spur would be constructed from the workshaft site to the existing line.

For the cost analysis, it was anticipated that no muck removal would take place at this site and that Workshaft #A1 would be used for both removal of the TBM and as an exit shaft for emergency purposes. Although no muck removal would take place at this site, the logistical upgrades as described above (1,200 ft of connecting road and the 500 ft railroad spur) and their associated costs would remain as part of this alternate. These upgrades would most likely be needed for the ingress and egress of men and material during the construction of the workshaft itself as well as during the construction of the main tunnel.

The major drawback with this site occurs in the tunnel segment south of this location and just north of the Two Bridges Inlet. A very high likelihood of encountering an adverse mixed faced tunnelling condition exists in the vicinity of the glacial era "plunge pool". The "plunge pool" with a bedrock low near sea level, has been identified between the Pompton Inlet and this location. It has been estimated that costly mixed face (combined hard rock to soft ground and back to hard rock excavation) tunnelling with associated structural support would range from $30,000 to $35,000 per lineal foot to maintain the tunnel profile above sea level. To avoid the "plunge pool", the tunnel would have to be constructed well below sea level and construction costs would increase due to higher energy requirements at the workshaft. Annual costs would also increase due to higher operation and maintenance costs. With the profile of this tunnel alignment lowered below sea level in order to avoid the plunge pool, a second pumping system similar to the one used at Workshaft #2C of the Selected Alignment would be installed to maintain the tunnel in a dry condition.

b. Workshaft #A2. The purpose of this workshaft is for the removal of tunnel muck.

A field investigation was made to determine the feasibility of this site as a workshaft. The site would be located in Cedar Grove Township, Essex County, New Jersey, near the old railroad station just west of Route 23. The workshaft would be situated on the tunnel alignment and lie 18,000 linear feet south of the Two Bridges Inlet.

With a distance of nearly 11 miles between the previous workshaft #A1 and the next downstream workshaft at #A3, a workshaft in this general area is needed, because this tunnel bore length is double the optimum distance. Although no ideal workshaft in this general area could be found, the selected site for workshaft #A2 was considered the best after reviewing the available locations along and adjacent to the proposed tunnel alignment. Therefore, with no other functional alternative, this less than suitable site is proposed for this alignment with substantial logistical upgrades.

Without sufficient area, permanent on-site storage was eliminated. The surrounding area is developed commercially. Muck removal by trucks would prove to be inefficient and most likely infeasible. The nearest major highway to the area is Pompton Turnpike which consists of a narrow two lane shouldered highway with commercial development along its route. There is no room for widening the highway and therefore the road would have to be used in its present state. Without roadway widening, significant ingress and egress problems would result due to large numbers of heavy trucks clogging the town highways. Traffic delays, breakdowns, along with associated inconveniences to local residents would result in significant disruption to the community with this muck removal method.

To effectively and efficiently remove tunnel muck from this site, only railroad cars would seem feasible. However, the railroad tracks that existed some 10 -15 years ago have long been removed with the remaining right-of-way (ROW) now used as a popular recreation trail. A major rehabilitation to this line would have to be accomplished in order to make it operational. This would include, but not be limited to, the installation of approximately 10,000 linear feet of railroad track as well as the major overhaul of an existing railroad bridge that crosses Route 23. This scenario would remove from use a well used recreational trail and disrupt local neighborhoods which have made more intensive use of the adjacent lands since the track bed was abandoned and removed.

c. Workshaft #A3. The purpose of this workshaft is for removal of tunnel muck.

This workshaft site would be located in the City of Newark, Essex County, New Jersey, in the northerly portion of Branch Brook Park. The workshaft would be situated on the tunnel alignment and lie 29,500 ft south of Workshaft #A2.

The area surrounding this site is highly urbanized with narrow and congested arterial highways. For this reason, any highway upgrading would be severely restricted by the lack of existing lands that could be used for ROW takings. Any attempt at using the existing and surrounding road network for truck transport of the muck material would prove to be impractical if not impossible. Permanent on-site storage is not an option at this area. Therefore, the only remaining option would be railroad transport of the tunnel muck. The existing railroad in this area is elevated and in order to make this operation feasible, a 1,500 linear foot railroad spur through intensively used city parklands would have to be constructed at a point close to the existing track. A vertical conveyor would then be used to lift the tunnel muck to the existing tracks for transport to a disposal site. This is not an ideal situation and a configuration such as this, would be vulnerable to back-ups, breakdowns and delays.

2. Geotechnical Design. As discussed in III.A.2., all of the considered alignments are feasible. However, the existence of a bedrock low (plunge pool) near the Mountainview area of Wayne Township may require this alignment's profile to be constructed almost entirely below sea level or be routed around this feature. Lowering the tunnel would necessitate additional dewatering requirements and sediment removal (O & M). The limits of this bedrock low will need to be defined during the subsurface explorations, if this alignment is considered a viable alternative. This route approaches the basalt formations at a lower angle of intersection, increasing the length of basalt to be excavated by 3,500 feet.

3. Hydraulic Design. Main tunnel. The frictional length used in this analysis was 106,715 ft. The resultant tunnel diameter would be unchanged from the selected alignment. See Table H1.

Spur tunnel. This plan would directly connect the Pompton Inlet to the Two Bridges Inlet. Therefore, no spur tunnel would be required.

4. Cost Engineering. The costs shown for the inlets (2), outlet (1) and shafts (5) were extrapolated from the Selected Alignment ($58,650,000) and rounded to $60,000,000 due to the preliminary nature of the estimate. As noted below, TBM advance rates were used to determine the period of construction and the average daily cost for excavation of the Selected Alignment was used to develop a total excavation cost for the main tunnel. Average daily costs for constructing the concrete lining on the Selected Alignment were also used to estimate these costs for alternate alignments. Although <u>not</u> used in the cost estimate shown below, the following factors would greatly impact on the final cost of this Alternate Plan A:

- o The interest during construction (IDC) would increase with the lengthening of the construction period and thereby reduce economic feasibility. For comparison purposes, as stated earlier the IDC for the main tunnel of the Selected Plan was estimated at approximately 29% of the first cost.

- o There is a strong possibility of the TBM encountering mixed-faced tunnelling through the "plunge-pool" area north of the Two Bridges Inlet. Based on limited information to date, it has been estimated that the length of this reach could vary greatly and range 1,000 to 2,500 feet in length. Should mixed-faced tunnelling occur, costs would increase significantly in this reach. It has been estimated that mixed-faced tunnelling would cost approximately $30,000 per lineal foot.

- o Due to the highly urbanized nature of the surrounding neighborhoods and the limited access arterial roadway network in and around the areas between Workshafts #A1, #A2 and #A3, a strong potential for possible delays, slowdowns or logistical problems exists in muck removal and/or the movement of men, trucks and heavy equipment through residential streets. Therefore, anticipated progress rates in excavation and concreting could be reduced due to logistical problems on the surface. These delays could increase time for the excavation progress and the concrete production.

Without encountering mix-faced tunneling and ignoring possible delays, slowdowns or surface logistical problems the costs for this plan were estimated as follows:

Main Tunnel

Inlets, Outlet and Shafts	= $	60,000,000
Excavation:		
Sedimentary - 86,150 lf @ 100 lf/day	=	862 days
Basalt - 20,000 lf @ 50 lf/day	=	400 days
Total		1,262 days
1,262 days @ $449,000 per day	= $	566,638,000
Concrete Lining:		
106,150 lf @ 230 lf/day	=	462 days
462 days @ $564,000 per day	= $	260,568,000
Additional Costs:		
Workshaft #A1		
Deeper shaft with pump station	= $	10,000,000
1,200 lf connecting road	= $	200,000
500 lf railroad spur	= $	250,000
Two Bridges Inlet		
Special underground connecting chamber	= $	3,000,000
Workshaft #A2		
10,000 lf new rail line	= $	7,500,000
New railroad bridge	= $	5,500,000
Workshaft #A3		
1,500 lf railroad spur	= $	750,000
Vertical conveyor	$	3,500,000
Sub-Total	= $	917,906,000
Spur Tunnel		
Not needed	= $	0
Real Estate (See paragraph below)	= $	7,555,000
Plan A Total Tunnel Cost (Incl. Real Estate)	**= $**	**925,461,000**

5. **Real Estate.** Based on the Selected Alignment, the real estate costs for plan A are as follows:

Ancillary Real Estate Costs:		
Workshaft #A1	= $	600,000
Workshaft #A2	= $	2,800,000
Workshaft #A3	= $	425,000
Surface Easements:		
Workshafts (5), Inlets (2), Outlets (1)	= $	2,900,000
Sub-Surface Easements:		
Tunnel - 106,150 lf or $6.24/lf	= $	663,000

Administrative Costs:
Planning, Surveys,
Appraisals and Administration
- 106,150 lf or $1.57/lf = $ 167,000

Administrative Costs: Planning, Surveys, Appraisals and Administration - 106,150 lf or $1.57/lf	= $	167,000
Total Cost	= $	7,555,000

6. Operation and Maintenance In order to avoid the "plunge pool" north of the Two Bridges Inlet, the entire tunnel length below Two Bridges Inlet would be built below sea level. This would require an additional pump station similar to the one at Workshaft #2C of the Selected Alignment to be installed at Workshaft #A1, since the length of tunnel below sea level would be almost twice that of the Selected Alignment.

Based on the costs for the Selected Alignment, the annual O & M costs for Plan A were estimated as follows:

Item	Cost
Pump Out	$ 615,000
Silt Removal	$ 250,000
Salaried Personnel	$ 310,000
Clean Out & Maintain	$ 270,000
Miscellaneous	$ 50,000
Total Annual O & M Cost	$ 1,495,000

B. Plan B

1. Physical Features. The basic features of Plan B, as shown on Figure F4, consist of a straight tunnel run from the Pompton Inlet 86,800 ft south directly to Workshaft #2B. This straight line run results in the shortest main tunnel length between the Pompton Inlet site and Newark Bay. The overall distance is 104,200 ft which makes this plan 1,800 ft shorter than the Selected Plan. The Spur Tunnel would increase in length from 6,500 lf to 9,000 lf.

The advantages of this plan would be:

- Shortest main tunnel route
- Elimination of bends in the tunnel

The disadvantages of this plan would be:

- Lack of suitable workshaft locations
- Longer length of spur tunnel
- Longer construction duration therefore more IDC
- Strong likelihood of increased costs due to delays, slowdowns and/or logistical problems
- TBM will have to bore through a longer reach of basalt rock

a. Workshaft #B1. The purpose of this workshaft is for removal of tunnel muck.

A field visit was made at this proposed workshaft to evaluate its viability. The site is located in Totowa Boro, Passaic County, New Jersey in an area just north of Route 46 and lying between Minnisink Road on the west and Union Ave to the east. It would be situated directly on the tunnel alignment and would lie 30,800 linear feet south of the Pompton River Inlet Site.

The area surrounding the proposed site is highly industrialized with many factory type industries in the neighborhood. This site would permit two options for muck removal: truck and railroad. Since the site is situated directly off Route 46 and just south of Route 80, this makes the site an ideal location for muck removal by truck. Also, the Erie Lackawanna railroad passes just directly north of this site. A 1,000 foot spur through a very confined industrial area would be needed to make this connection.

The major disadvantage of the site is the lack of open space. It does not appear feasible that 5 acres would be available at this location without the costly acquisition of a business and property. The size of open space was estimated to be no more than 2 acres. Therefore, on-site storage of muck along with sufficient area to house temporary construction trailers and store construction materials would have to be kept to a minimum.

Without the capability for temporary storage of excavated muck along with a smooth flow of construction men and materials throughout the area, TBM and concrete production rates could be seriously impacted (lower TBM advance rates).

b. Workshaft #B2. The purpose of this workshaft is that it is to be used as either a "hook hole" workshaft (similar to Workshaft #2A of the Selected Alignment), or as an exit shaft for the TBM and or emergency purposes.

This site was reviewed during a field visit. The site is located in Montclair Town, Essex County, New Jersey in the northwest corner of Brookdale Park. This is an active, well kept park surrounded by a quiet, peaceful residential neighborhood. The proposed workshaft would be sited directly on the tunnel alignment and would lie 24,000 feet south of Workshaft #B1. The site would be situated directly in the center of a highly affluent residential neighborhood, with home values ranging from $500,000 to over $1,000,000. With the constant movement of heavy machinery through the residential streets and the use of the park as a construction site, significant neighborhood opposition would most likely occur.

This potential workshaft site is not adjacent to any major highway. The nearest highway would be the Garden State Parkway which normally does not permit truck traffic. Since this area is densely populated, no land appears to be available for a ROW to improve the capacity of the existing streets. No major railroad is located around this site, nor are there any other suitable sites are located within the vicinity of this less than ideal site.

c. **Workshaft #B3.** The purpose of this workshaft is for the removal of tunnel muck.

A site visit was made to this area to verify the viability of this proposed workshaft. The area is located in Belleville Town, Essex County, New Jersey in the northwest corner of the Hendricks Field County Golf Course. It is situated directly on the tunnel alignment and would be 15,000 feet south of Workshaft #B2.

The Hendricks Field County Golf Course is a well kept active facility. In order to use this potential workshaft site to its full extent for muck removal, while at the same time maintain a high quality facility for the individuals who use the golf course, it may be necessary to alter the existing golf course to accommodate the taking of land necessary for the workshaft site. The golf course encompasses an area of approximately 50 acres. The potential workshaft site would need at least 5 acres. The remaining 45 acres would then have to be modified to accommodate a usable 18 hole golf course.

This site is situated in the middle of a highly residential area. The surrounding road network is comprised of narrow neighborhood streets and no major highways are in the immediate area. Therefore, the only possible transportation method for muck removal would be by railroad. To accomplish this, a 4,000 ft. railroad spur would have to be constructed along the westerly boundary of the golf course to reach the proposed workshaft site. No other workshaft sites are located within the vicinity of this less than ideal site.

2. **Geotechnical Design.** Refer to paragraph III.A.2. The orientation of this alignment may be less favorable as related to the structural geology (especially through the Totowa/Little Falls area). This alignment may require additional excavation through fault zones and rock contacts due to the lower angle of intersection. If so, additional support and construction difficulties should be anticipated over longer lengths of the tunnel. Also, the length of tunnel constructed in basalt will increase due to the oblique angle of penetration. This will increase construction time because of slower penetration rates in the basalt formation.

3. Hydraulic Design. Main tunnel. The frictional length used in this analysis was 104,765 ft. The length included the vertical drop at the Pompton Inlet and the vertical rise at the outlet shaft at Newark Bay. The resultant tunnel diameter would be reduced by 0.15 feet from that of the Selected Alignment. This plan results in the shortest length between the Pompton Inlet and the Newark Bay outlet (straight line). There is one horizontal bend (at the outlet) and this alignment would result in the smallest tunnel diameter.

Spur tunnel. The frictional length used in this analysis was 9,130 ft. The length included the 130 ft vertical drop at the Two bridges Inlet. The resultant spur tunnel diameter would be increased by 1.0 feet over the spur tunnel dimension of the selected alignment.

4. Cost Engineering. The costs shown for the inlets (2), outlet (1) and shafts (5) were extrapolated from the Selected Alignment ($58,650,000) and rounded to $60,000,000 due to the preliminary nature of the estimate. Main tunnel costs are determined as described for Alternate Plan A. Spur tunnel costs are based on the cost of the 22 foot diameter spur tunnel for the selected alignment. Although <u>not</u> used in the cost estimate shown below, the following factors would greatly impact on the final cost of this Alternate Plan B:

- o The interest during construction (IDC) would increase with the lengthening of the construction period and thereby reduce economic feasibility. For comparison purposes, as stated earlier, the IDC for the main tunnel of the Selected Plan has been estimated at approximately 29% of the first cost.

- o Due to the lower angle of intersection, this tunnel bore may require additional excavation through fault zones and rock contacts. Should this condition be encountered, additional support (rock bolts, steel ribs, shotcreting, etc) would be required. Associated construction delays and difficulties should also be anticipated.

- o The spur tunnel increased in length 2,500 lf over that used in the Selected Plan. In order to maintain the same flow capacity, the diameter of the tunnel would have to be increased. Although the larger size of the spur tunnel will increase costs, the added length is the major reason for cost increases on the spur tunnel. The cost shown therefore is low, but adequate for comparison purposes.

- o As described in Alternate Plan A, this plan would also have a strong potential for possible delays, slowdowns or logistical problems in muck removal and/or problems with the movement of men, trucks and heavy equipment through the areas in and around Workshafts #B1, #B2 and #B3. The majority of the surrounding areas are quiet residential neighborhoods with luxurious homes. The comprising roadway network is made up of small narrow streets not all suited for heavy daily construction traffic. In addition, there are no major highways in the immediate vicinity. Muck transport would have to rely solely on the use of nearby existing railroads for removal. Any slowdowns, mechanical breakdowns or significant surface interruptions would seriously hinder the progress of the TBM. Concrete progress would also be affected by the limited roadway capability through delays and logistical problems. The area to the north around Workshaft #B1 is highly industrialized with many factories and very little open space. Sufficient staging area is needed in and around the workshaft site to support the movement of men and materials and to stockpile the excavated muck while awaiting its removal. If any of these major problems were to occur due to these constraints, and there is a strong likelihood that they would, progress and production rates in both excavation and concreting would be significantly reduced. These delays could add additional time to the excavation progress and the concrete production and therefore subsequently increase costs significantly.

Therefore, without accounting for any of the following: (1) the possible geotechnical problems and their costs that might occur due to the lower approach angle through the fault zones and rock contacts, (2) the larger diameter spur tunnel that would be needed due to its increased length, and (3) the potential for delays, slowdowns or logistical problems -- then costs for this Alternate Plan B may be estimated as follows:

<u>Main Tunnel</u>

Inlets, Outlet and Shafts	=	$ 60,000,000
Excavation:		
Sedimentary - 83,200 lf @ 100 lf/day	=	832 days
Basalt - 21,000 lf @ 50 lf/day	=	420 days
Total		1,252 days
1,252 days @ $449,000 per day	=	$ 562,148,000

Concrete Lining:

104,200 lf @ 230 lf/day	=	454 days
454 days @ $564,000 per day	= $	256,056,000
Additional Costs:		
Workshaft #B1		
1,000 lf railroad spur	= $	500,000
Workshaft #B3		
Relocate golf course	= $	4,500,000
4,000 lf railroad spur	= $	2,000,000
Sub-Total	= $	885,204,000
<u>Spur Tunnel</u>		
9,000 lf @ $6,850	= $	61,650,000
<u>Real Estate</u> (See paragraph below)	= $	11,035,000
Plan B Total Tunnel Cost (Incl. Real Estate)	**= $**	**957,889,000**

5. Real Estate. Based on the Selected Alignment, the real estate costs for Alternate Plan B are as follows:

Ancillary Real Estate Costs:		
Workshaft #B1	= $	5,500,000
Workshaft #B2	= $	1,102,000
Surface Easements:		
Workshafts (6), Inlets (2), Outlets (1)	= $	3,543,000
Sub-Surface Easements:		
Tunnel - 113,200 lf or $6.25/lf	= $	708,000
Administrative Costs:		
Planning, Surveys,		
Appraisals and Administration		
- 113,200 lf or $1.60/lf	= $	182,000
Total Cost	= $	11,035,000

6. Operation and Maintenance The costs for this Alternate Plan B would be the same as those used in the Selected Alignment.

C. Plan C

1. Physical Features. The basic features of Alternate Plan C, as shown on Figure F-5, consist of a straight tunnel run from Workshaft #3 of the Selected Alignment 63,900 ft south directly to Workshaft #2B. The overall distance is 104,400 ft which makes this plan 1,600 ft shorter than the Selected Plan. The spur tunnel would increase in length 500 lf from 6,500 lf for a total distance of 7,000 lf.

The advantages of this plan would be:

- Shorter main tunnel route
- Elimination of bends in the tunnel

The disadvantages of this plan would be:

- o Lack of suitable workshaft locations
- o Longer length of spur tunnel
- o Longer construction duration therefore more IDC
- o Strong likelihood of increased costs due to delays, slowdowns and or logistical problems
- o TBM will have to bore through more basalt rock

a. Workshaft #C1 The purpose of this workshaft is for the removal of tunnel muck.

A field visit was made of this area. This potential workshaft would be located in Cedar Grove Township, Essex County, New Jersey just southeast of the Cedar Grove Reservoir in an area known as Davella Mills County Park. It would be situated directly on the tunnel alignment and would lie 23,400 linear feet south of the Workshaft #3.

This site is located in a steep-sloped wooded area at the westerly base of the Watchung Mountains near the Cedar Grove Reservoir. The surrounding area is primarily residential with narrow winding roads. Some roads are fairly steep as they pass over small mountains. These steep inclines would be a factor for trucks to contend with since it is anticipated at this time that tunnel muck would be removed from this area off-site by truck. Cycle times for round trip truck runs would be reduced due to low speeds and slowdowns. The steep slopes would also reduce truck dependability and reliability while also increasing the risk of traffic accidents and personal injury during any inclement and or hazardous weather.

The closest major highway is Route 23, and this two lane suburban road does not appear to be wide enough to handle the amount of truck traffic necessary for a major off-site muck removal operation. Therefore a tremendous potential for delays, slowdowns and a general overall increase in construction time would exist at this site.

As for railroads, the Erie-Lackawanna railroad is nearby, but due to the extremely steep slopes and necessity for numerous real estate takings, it would not be practical to build a spur to reach this location. Therefore, the only means of muck removal off-site would be by trucks.

With this workshaft to be used as a main source of muck removal, and given the limiting conditions as described above, alternate workshaft sites with muck removal capabilities were also investigated. The distance between this workshaft site (#C1) and workshaft site #C3 is 25,000 linear feet which exceeds the recommended optimum distance. That in itself would not be a major problem, but due to the fact that the ground surface infrastructure of the entire area is not conducive to muck removal, an additional site between these two was sought. This site, workshaft #C2 as described below, could also serve as a means of muck removal. This added site (#C2) would alleviate workshaft #C3 as the sole source of muck removal in this reach and thereby reducing the daily output at workshaft #C3.

An alternate workshaft site approximately 2,500 lf south of this proposed workshaft was also investigated for its potential. This site would be located in an area known as Mountainside park which lies in the middle of a heavily concentrated residential area. The entire park appears to contain approximately 12 acres. If a minimum of five acres were to be utilized for a workshaft operation, that would in effect reduce the existing park to half its size, thereby severely limiting its existing recreational benefits. It is generally anticipated that substantial local opposition would develop if any alteration were made to a park. Also, due to its location, this alternate would add approximately 600 lf to the entire length of the tunnel. This would add more time to the duration of, and more cost to the project. With all things being considered, this alternate workshaft site does not appear to be any more cost effective than the original one under consideration. Aside from this alternate workshaft, no other suitable sites are located within the vicinity of alternate Workshaft #C1.

b. Workshaft #C2. The purpose of this workshaft is for TBM removal and emergency ingress and egress with the potential for muck removal.

A field inspection was also made of this site to assess its viability. The potential workshaft site would be located in Montclair Town, Essex County, New Jersey in the southwest corner of Brookdale Park. It would be situated directly on the tunnel alignment and would lie 10,000 feet south of Workshaft #C1.

The site is located approximately 2,000 lf south of proposed site for workshaft #B2. The site also shares many of the same limitations and conditions that exist for Workshaft #B2. Therefore, the reader is referred to the description for Workshaft #B2. The same limited conditions that exist at Workshaft #B2 would also apply to this site.

c. Workshaft #C3. The purpose of this workshaft is for the removal of tunnel muck.

This potential workshaft site was also field checked to ensure its viability. The site is located in Belleville Town, Essex County, New Jersey in the southeast corner of the Hendricks Field County Golf Course. It would be situated directly on the tunnel alignment and would lie 15,000 feet south of Workshaft #C2 and approximately 1,000 lf south of proposed workshaft #B3 which is also located on the golf course. Therefore, the reader is referred to the description for workshaft #B3. The same limited conditions would also apply to this site.

2. Geotechnical Design. See paragraph III.A.2. Essentially this alignment has the same drawbacks as Plan B. See paragraph IV.B.2.

3. Hydraulic Design. Main tunnel. As noted on Table H1, the length of tunnel and number of horizontal and vertical bends are almost identical to Alternate Plan B. Since the length was only marginally increased and the horizontal and the vertical bends are minor losses, the main tunnel diameter in Plan B was used for this plan and results in a reduction of 0.15 feet when compared with the selected plan.

Spur tunnel. The frictional length used in this analysis was 7,130 ft. The length included the 130 ft vertical drop at the Two Bridges Inlet. The spur tunnel diameter would be increased by 0.25 feet over the Selected Alignment.

4. Cost Engineering. The costs shown for the inlets (2), outlet (1) and shafts (6) were extrapolated from the Selected Alignment ($58,650,000) and increased by $5,000,000 to account for the extra workshaft and then rounded to $65,000,000 due to the preliminary nature of the estimate. Main tunnel costs are estimated as described for Alternate Plan A. Spur tunnel costs are based on the cost of the 22 foot diameter spur tunnel for the Selected alignment. Although <u>not</u> used in the cost estimate shown below, the following factors would greatly impact on the final cost of this Alternate Plan C.

- o The interest during construction (IDC) would increase with the lengthening of the construction period and thereby reduce economic feasibility. For comparison purposes, as stated earlier the IDC for the main tunnel of the Selected Alignment has been estimated at approximately 29% of the first cost.

- o This alternate plan would also have a tunnel bore at a lower angle of intersection with the basalt formation than that of the Selected Alignment. Therefore it may require additional excavation through fault zones and rock contact zones. Should this condition be encountered additional support (rock bolts, steel ribs, shotcreting, etc) would be required. Associated construction delays and difficulties should also be anticipated.

- Again as described in Alternate Plan A, this plan too would have, to a greater degree than the others, an increased potential for delays, slowdowns or logistical problems in muck removal and/or problems with the movement of men, trucks and heavy equipment through the areas in and around Workshafts #C1, #C2 and #C3. The same limiting conditions that would apply for the previously described Workshafts #B2 and #B3 would also apply for this alignment. The area surrounding Workshaft #C1 would be especially subject to delays and slowdowns due to its rugged terrain and limited muck removal options. These delays could add additional time and significant cost to the excavation progress and concrete production.

Therefore, ignoring any possible geotechnical problems that might occur through the fault zones and rock contacts, and also discounting the potential for delays, slowdowns or logistical problems, the costs for this Alternate Plan C were estimated as follows:

<u>Main Tunnel</u>

Inlets, Outlet and Shafts	=	$ 65,000,000
Excavation:		
Sedimentary - 83,300 lf @ 100 lf/day	=	833 days
Basalt - 21,100 lf @ 50 lf/day	=	422 days
Total		1,255 days
1,255 days @ $449,000 per day	=	$ 563,495,000
Concrete Lining:		
104,400 lf @ 230 lf/day	=	454 days
454 days @ $564,000 per day	=	$ 256,056,000
Additional Costs:		
Workshaft #C1		
1,000 lf connecting road	=	$ 250,000
6,500 lf surrounding road upgrade	=	$ 1,000,000
Workshaft #C3		
Relocate golf course	=	$ 4,500,000
3,000 lf railroad spur	=	$ 1,500,000
Sub-Total	=	$ 891,801,000
<u>Spur Tunnel</u>		
7,000 lf @ $6,850	=	$ 47,950,000
<u>Real Estate</u> (See paragraph below)	=	$ 8,470,000
Plan C Total Tunnel Cost (Incl. Real Estate)	**=**	**$ 948,221,000**

5. Real Estate. Based on the Selected Alignment, the real estate costs for Alternate Plan C are as follows:

Ancillary Real Estate Costs:			
Workshaft #C1	=	$	1,500,000
Workshaft #C3	=	$	1,100,000
Surface Easements:			
Workshafts (7), Inlets (2), Outlets (1)	=	$	5,000,000
Sub-Surface Easements:			
Tunnel - 111,400 lf or $6.25/lf	=	$	695,000
Administrative Costs:			
Planning, Surveys, Appraisals and Administration - 111,400 lf or $1.57/lf	=	$	175,000
Total Cost	=	$	8,470,000

6. Operation and Maintenance The costs for Alternate Plan C would be the same as those used in the Selected Alignment.

D. Plan D

1. Physical Features. The basic features of Alternate Plan D, as shown on Figure F-6, consist of a straight tunnel run 25,500 ft south from The Pompton River Inlet site to Workshaft #D1 and then 20,000 ft directly to Workshaft #2 of the Selected Alignment. The remainder of this alignment would be the same as the Selected Alignment. The overall distance for this plan is 104,900 ft which makes this plan 1,100 ft shorter than the Selected Alignment. The Spur Tunnel would increase in length from 6,500 lf to 11,200 lf.

The advantages of this plan would be:

- o Shorter main tunnel route
- o Elimination of northern most bend at Two Bridges Inlet

The disadvantages of this plan would be:

- o Longest length of spur tunnel
- o Strong likelihood of increased costs due to delays, slowdowns and/or logistical problems
- o TBM will have to bore through a longer length of basalt rock

a. Workshaft #D1 The purpose of this workshaft is for TBM removal and emergency ingress and egress.

A field investigation was made to evaluate this location as a potential workshaft site. This proposed workshaft would be located in Totowa Boro, Passaic County, New Jersey in an area just south of Naachtpunkt Brook, lying between Totowa

Road to the east and Naachtpunkt Road to the west. The workshaft would be situated directly on the tunnel alignment and would lie 25,500 feet south of the Pompton River Inlet site.

The area surrounding this potential workshaft site can be classified as highly commercial/industrial and is presently undergoing intensive development. The availability of this site is at risk. If available, the logistics of removing the tunnel muck off-site remains. The site is far removed from major highways or railroads. For this reason the site would be recommended for TBM removal only. Muck removal would be accomplished at the Pompton River Inlet site, similar to the Selected Alignment.

b. Other Workshaft Locations. All other workshaft locations in Alternate Plan D would be identical to those of the Selected Alignment. Similar workshafts are #2, #2A, #2B and #2C.

2. Geotechnical Design. There appears to be no significant advantages or disadvantages to Plan D. However, there have been no subsurface investigations performed along the upper portion of the alignment to confirm this assumption.

3. Hydraulic Design. Main tunnel. As noted on Table H1, the length of tunnel, number of horizontal and vertical bends are almost identical to Alternate Plan B. Since the length was only marginally increased and the horizontal and vertical bends are such minor losses, the main tunnel diameter in Alternate Plan B was used for this plan and results in a reduction in diameter of 0.15 feet.

Spur tunnel. The frictional length used in this analysis was 11,330 ft, the longest of all alignments. The length included the 130 ft vertical drop at the Two Bridges Inlet. The spur tunnel diameter would be increased by 1.75 feet over the Selected Alignment.

4. Cost Engineering. The costs shown for the inlets (2), outlet (1) and shafts (5) were extrapolated from the Selected Alignment ($58,650,000) and rounded to $60,000,000 due to the preliminary nature of the estimate. All major workshafts for this alignment are the same as those for the Selected Alignment with the exception of Workshaft #D1. This workshaft is similar in location and will serve the same purpose as Workshaft #3 of the Selected Alignment. The cost difference in this alignment results from the longer spur tunnel. The excavation costs and construction duration for the main tunnel are nearly the same as for the Selected Alignment. Although <u>not</u> used in the cost estimate shown below, the following factors would greatly impact on the final cost of this Alternate Plan D.

- o The interest during construction (IDC) would increase with the lengthening of the construction period for the spur tunnel and thereby reduce economic feasibility. For comparison purposes, as stated earlier the IDC for the spur tunnel of the Selected Alignment has been estimated at approximately 11% of the first cost.

- o This Alternate Plan D would also have a tunnel bore at a lower angle of intersection with the basalt formation than that of the Selected Alignment. Therefore it may require additional excavation through fault zones and rock contact zones. Should this condition be encountered additional support (rock bolts, steel ribs, shotcreting, etc) would be required. Associated construction delays and difficulties should also be anticipated.

Therefore, ignoring any possible geotechnical problems that might occur through the fault zones and rock contacts, the costs for this Alternate Plan D were estimated as follows:

<u>Main Tunnel</u>

Inlets, Outlet and Shafts	= $	60,000,000
Excavation:		
Sedimentary - 87,400 lf @ 100 lf/day	=	874 days
Basalt - 17,500 lf @ 50 lf/day	=	350 days

Total		1,254 days
1,254 days @ $449,000 per day	= $	549,576,000
Concrete Lining:		
104,900 lf @ 230 lf/day	=	457 days
457 days @ $564,000 per day	= $	257,748,000

Sub-Total	= $	867,324,000
<u>Spur Tunnel</u>		
11,200 lf @ $6,850	= $	76,720,000
<u>Real Estate</u> (See paragraph below)	= $	4,451,000

Plan D Total Tunnel Cost (Incl. Real Estate)	**= $**	**948,495,000**

5. Real Estate. Based on the Selected Alignment, the real estate costs for Alternate Plan D are as follows:

Surface Easements:		
Workshafts (6), Inlets (2), Outlets (1)	= $	3,543,000

Sub-Surface Easements:			
Tunnel - 116,100 lf or $6.24/lf	=	$	725,000
Administrative Costs:			
Planning, Surveys,			
Appraisals and Administration			
- 116,100 lf or $1.57/lf	=	$	183,000
Total Cost	=	$	4,451,000

6. Operation and Maintenance The costs for Alternate Plan D would be the same as those used in the Selected Alignment.

E. Other Alignments. Other options were considered which varied the lower portion of the tunnel (See Figure F-7). Because of the difficulty in locating a suitable workshaft in the highly urbanized Nutley/Bellville area, this office considered extending the tunnel southward from the recommended plan outlet at Nutley/Clifton border to Newark Bay. This option was much more costly because of the significant additional tunnel length and was also ruled out because of the presence of a maze of old underground copper mines located in North Arlington along the route.

Other routes were considered from the Montclair Workshaft #2 to Newark Bay both east and west of the Selected Alignment to take advantage of any potential workshaft sites. Routes to the east were to utilize workshaft sites along the river for barge transportation and access to railroads for muck disposal, but no acceptable sites were available. In addition, the tunnel routes were longer and therefore these options became cost prohibitive. There were no suitable workshaft sites for a westerly route due primarily to intense residential development. Workshaft #2A, on the direct alignment between Workshafts #2 and #2C was then selected as the best alternative. This site, known as the "hook hole" workshaft, would provide access for dismantling the TBM cutterhead as described in paragraph III.A.1.f., Workshaft #2A.

V. Conclusions.

A. General. To date, this document indicates that the selected alignment holds key advantages over the alternative alignments. Those key advantages include the following:

- Fully functional workshafts
- Multiple transportation options for tunnel muck removal
- Shortest construction duration of tunnel elements
- Minimum boring length through basalt formations
- Greater degree of certainty due to ongoing subsurface explorations

Based on the above, the work accomplished to date and the more detailed documentation provided in this paper, the Preconstruction and Engineering Design (PED) should continue to focus on the Selected Alignment. Results of all new studies and the ongoing subsurface exploration program will be used to continually update and modify design parameters considered critical to the success of the implementation of the much needed diversion tunnels.

B. Geotechnical Design. From a geotechnical viewpoint, none of the alternate alignment plans appear to have any advantages over the present Selected Alignment. In fact, there are several disadvantages such as the additional excavation in basalt and longer tunnelling in fault zones, within each of the alternate alignments. Unless other considerations indicate a different alignment would be more appropriate, the present alignment appears to be the most suitable as related to geology.

C. Hydraulic Design. As noted in this analysis, the main tunnel diameter is relatively insensitive to tunnel alignment. Main tunnel diameters vary by 0.15 feet between plans and this difference for a tunnel of this magnitude is considered insignificant. Various alignments also require more horizontal or vertical curves, however these form losses are small when compared to the frictional losses developed with the long tunnel length. Table H1 summarizes these variables.

For the spur tunnel, the tunnel lengths vary significantly as Alternate Plan A has no spur tunnel and Alternate Plan D has a length of 11,200 feet. Comparison between plans show that spur tunnel diameter would increase by 1.75 feet for a given discharge (when compared to the Selected Alignment) or the flow capacity would vary between plans (those having a spur tunnel) by as much as 1,500 cfs for a given tunnel diameter. Table H1 also summarizes these variables.

D. Cost Engineering. When compared to the Selected Alignment, the additional boring length within the harder basalt formation in alternatives A, B, and C yields slower excavation and longer construction durations, thereby resulting in cost increases for these alignments. The additional cost of the lengthened spur tunnel in alternatives B, C, and D offsets savings in main tunnel length for these plans. For alternative A, the lack of need for a spur tunnel is offset by the longer main tunnel and increased surface costs associated with surface logistical upgrades, as well as the need to provide an underground chamber that would direct the spur tunnel inlet flow into the main tunnel with a minimal impact on the main tunnel flows, plus the construction of an additional pump station at Workshaft #A1.

Not included in these costs is the interest during construction which would increase above that of the Selected Alignment in proportion to cost increases and the longer duration of construction.

Finally, a major cost and constructability factor is the need for each alternative to have fully functional workshafts for construction of the alternative alignments. Workshafts and the surrounding area must have the capability to remove the tunnel muck as the material is brought to the surface, or the ability to provide temporary storage should surface problems arise (ie, weather, delays, slowdowns, equipment breakdowns, other). Limitations and constraints placed on the contractor at these critical work areas would ultimately increase the contractors bid price. Therefore, a reduction in progress rates and efficiency should be reflected in higher excavation and concrete lining costs for the main tunnel at the constrained workshafts shown in alternatives A, B, and C. However, these rates are difficult to quantify and it would take a great deal of effort to determine these reduced progress rates for each alignment. Such an effort was not warranted for this study. Arbitrary rate reduction factors were considered but not found to be quite satisfactory for this analysis. These factors were not included in the cost estimates and all workshafts were treated equally.

The costs provided, as given in Table C1 demonstrate that the Selected Alignment is the least costly alternative, based on all available information known at this time. It should be noted that Alternate Plan A could have significant cost increases that are not quantified in the cost estimate but qualified in this report. Mixed faced tunneling due to the unexpected encounter of the "plunge pool" or the strong possibility of surface interruptions delaying the movement of tunnel muck away from the workshaft site would significantly increase the cost of this alternative. Any reduction in progress rates would be arbitrary and were not used for this comparison. Therefore, it is highly likely that Alternatives A, B, and C would actually have higher costs than those shown.

VI. Recommendations.

The work accomplished to date does not indicate that any of the alternative alignments would be a superior or equal alternative to the Selected Alignment. Rather the data supports the Selected Alignment as the least costly plan when all workshafts are treated equally. Although not quantified in this report, alternate alignments A, B, and C would be subjected to a high probability of surface interruptions interfering with TBM and concrete lining production rates. Should production rates become reduced due to surface logistical problems, the overall TBM utilization factors would be decreased with a corresponding increase in construction duration. This would negatively affect parameters used in the evaluation of the economics of the project including the advance year benefits to the project and interest during construction (IDC).

From a geologic and hydraulic perspective any of the alignments are feasible and alternate alignments result in minor differences. However, the penetration angle of the alternate alignments does impact on the boring length through the harder basalt formations and therefore, all alternative alignments would have longer construction durations. Therefore, associated tunnelling costs would be expected to increase for these alternatives.

Based on the above, and the documentation provided in the report, the PED effort should continue to focus on and design the Selected Alignment. As part of the design process, care must be exercised to fundamentally review all geotechnical information as the drilling program progresses. In addition, the tunnel design layout must be continually reviewed and updated as new information becomes available. All new information, particularly in the areas of hydraulics, geotechnical design, cost engineering and real estate, will be critically reviewed to identify any needed adjustments to the Selected Alignment. Due to the overriding need for the key workshaft sites along the selected alignment, coordination with the local sponsor should focus on early acquisition and preservation of the inlet and workshaft areas for eventual use during tunnel construction.

TABLE C1

Summary of Costs for the Newark Bay Alignment

Physical Feature	Selected Alignment	A **	B **	C **	D
Main Tunnel					
Basalt * (ft)	16500	20000	21000	21100	17500
Sedimentary * (ft)	89500	86150	83200	83300	87400
Total Length (ft)	106000	106150	104200	104400	104900
Const Dur (mo)	71	73	72	72	71
# of Workshafts	5	5	5	6	5
Cost ($1,000s)	868650	917906	885204	891801	867324
Spur Tunnel					
Basalt * (ft)	2500	0	2500	2500	2500
Sedimentary * (ft)	4000	0	6500	4500	8700
Total Length (ft)	6500	0	9000	7000	11200
Const Dur (mo)	24	0	26	25	28
# of Workshafts	1	0	1	1	1
Cost ($1,000s)	44513	0	61650	47950	76720
Real Estate					
Cost ($1,000s)	4422	7555	11035	8470	4451
Total Cost($1,000s)	**917585**	**925461**	**957889**	**948221**	**948495**
Operations and Maintenance					
Annual Cost(1,000s)	825	1495	825	825	825

* Linear feet of rock type estimated by overlaying the various alignments on geologic maps and scaling the horizontal distance off the maps.

** Costs identified above are based on all workshafts being treated equally. Alternate Alignments A, B and C could be subjected to significant cost increases, such as those that would occur due to surface logistical problems, etc. See text for more detailed information.

TABLE H1

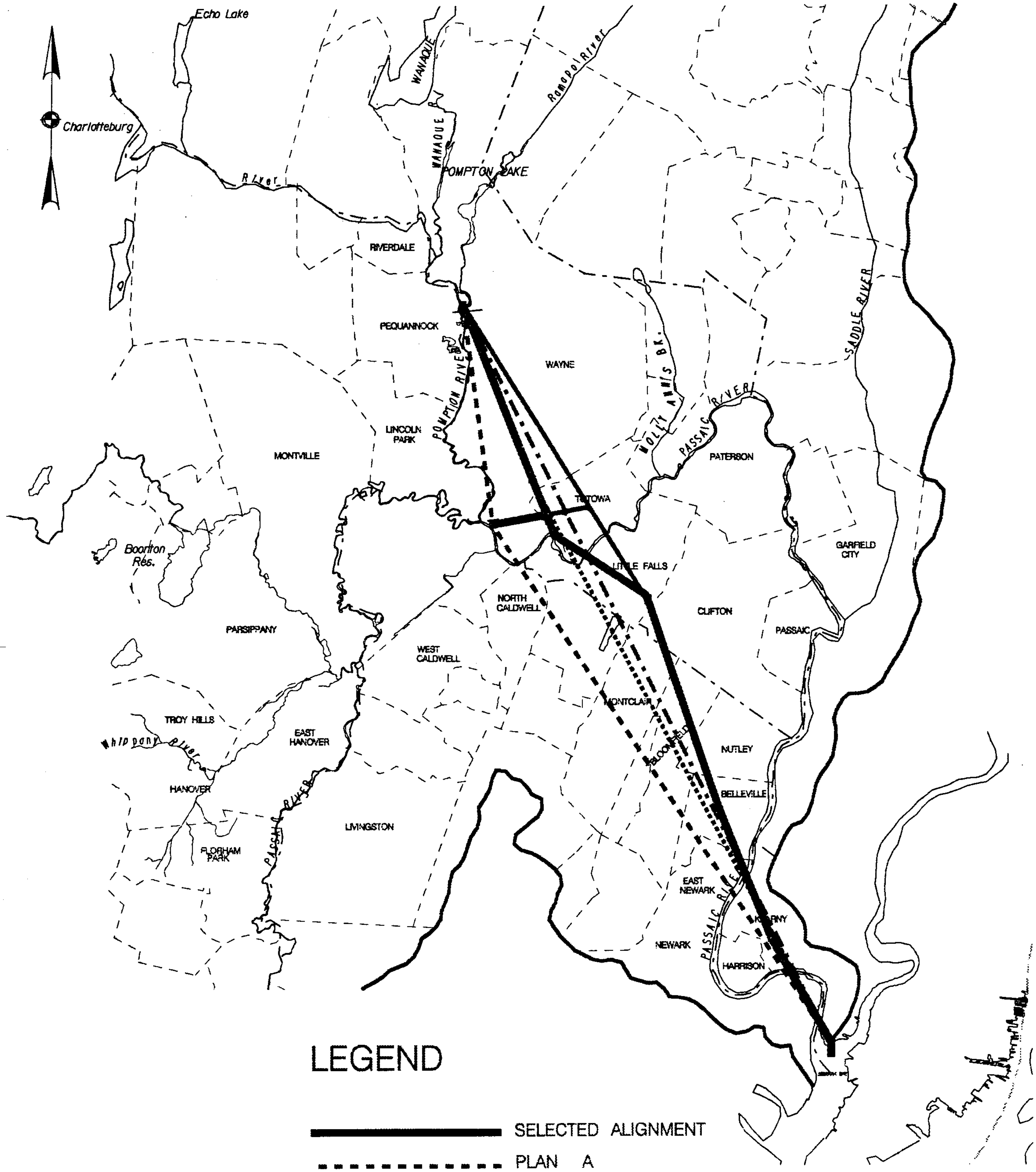
Hydraulic Considerations for the Newark Bay Alignment

Physical Feature		Selected Alignment	A	B	C	D
Main Tunnel:						
Length	(ft)	106000	106150	104200	104300	104900
# Horizontal Bends*		3	2	1	2	2
# Vertical Bends		4	4	4	4	4
Relative change in diameter	(ft)	0	0	-0.15	-0.15	-0.15
Spur Tunnel:						
Length	(ft)	6500	0	9000	7000	11200
# Horizontal Bends		1	N/A	1	1	1
# Vertical Bends		1	N/A	1	1	1
Relative change in diameter	(ft)	0	N/A	+1.0	+0.25	+1.75

* Significant deflections only.

Notes:
See Figure F1 for plan view of tunnel alignments.

PASSAIC RIVER FLOOD PROTECTION PROJECT



LEGEND

SELECTED ALIGNMENT
PLAN A
PLAN B
PLAN C
PLAN D

Figure F-1

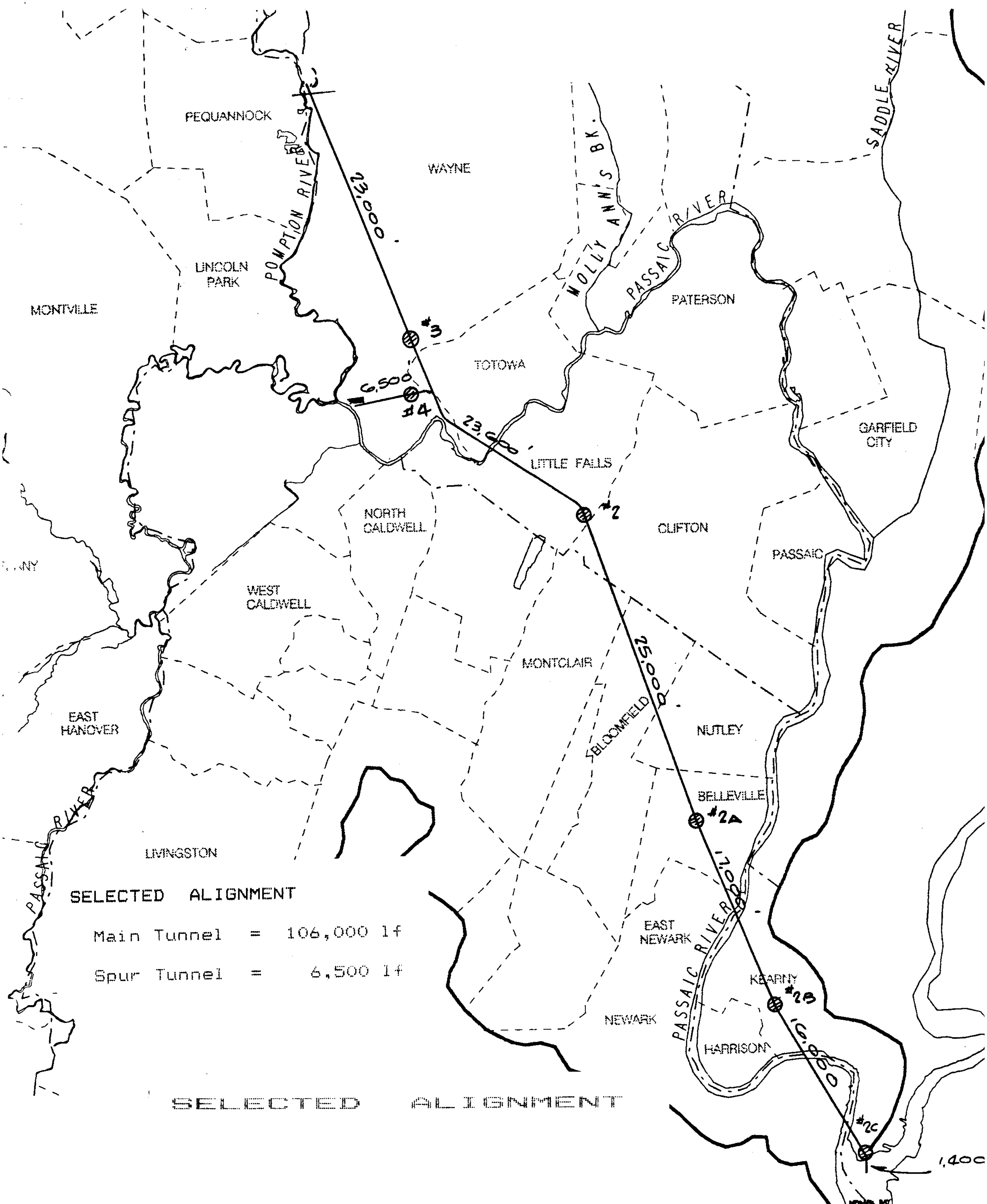
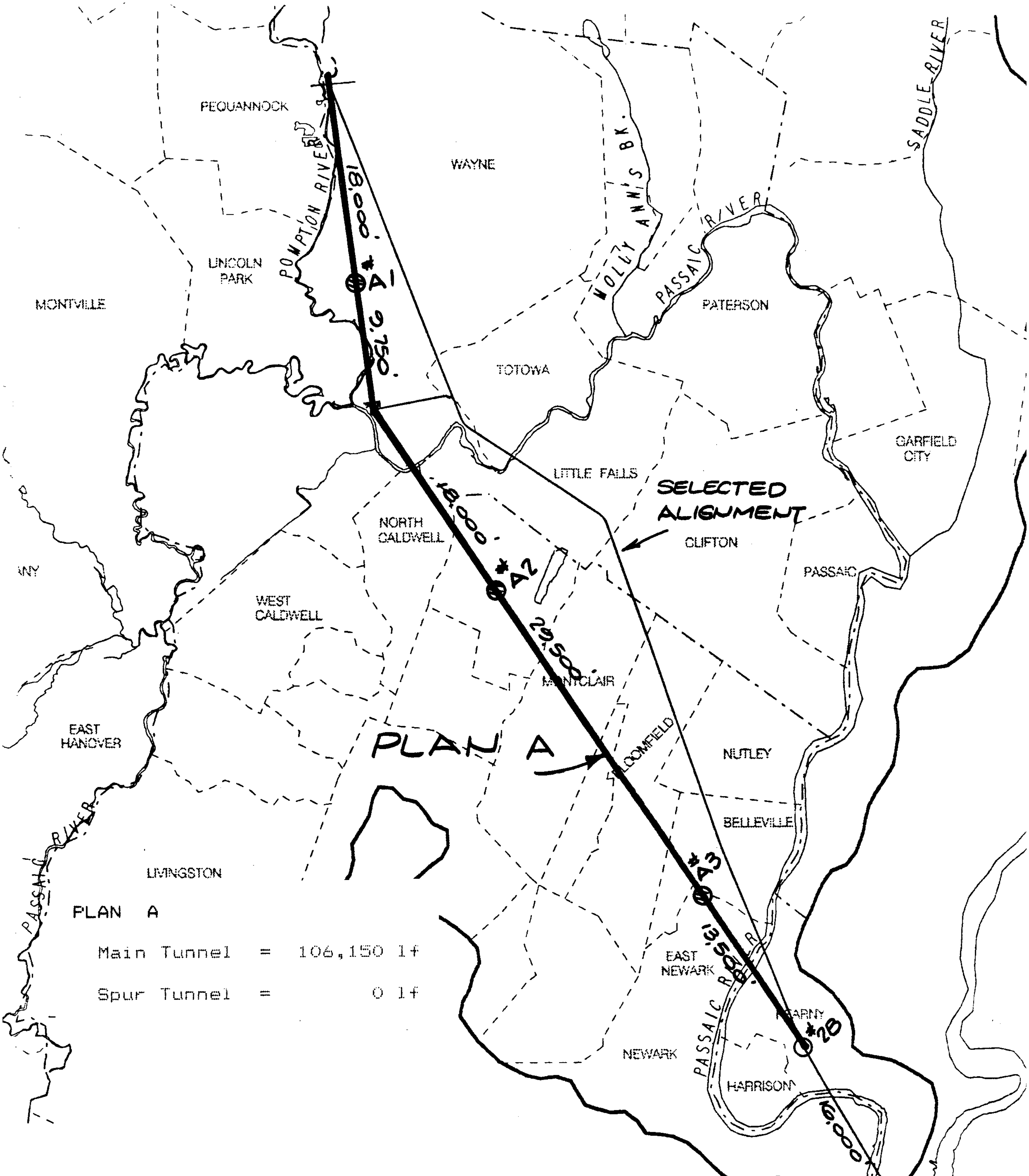

PEQUANNOCK
WAYNE
POMPTON RIVER
23,000
MOLLY ANN'S BK.
PASSAIC RIVER
SADDLE RIVER
LINCOLN PARK
MONTVILLE
PATERSON
#3
TOTOWA
6,500
#4
23,000
LITTLE FALLS
GARFIELD CITY
#2
NORTH CALDWELL
CLIFTON
PASSAIC
WEST CALDWELL
MONTCLAIR
25,000
BLOOMFIELD
NUTLEY
EAST HANOVER
BELLEVILLE
#2A
PASSAIC RIVER
LIVINGSTON
17,000
SELECTED ALIGNMENT
Main Tunnel = 106,000 lf
Spur Tunnel = 6,500 lf
EAST NEWARK
KEARNY
#2B
NEWARK
HARRISON
16,000
#2C
1,400
SELECTED ALIGNMENT

Figure F-2



PLAN A

Figure F-3

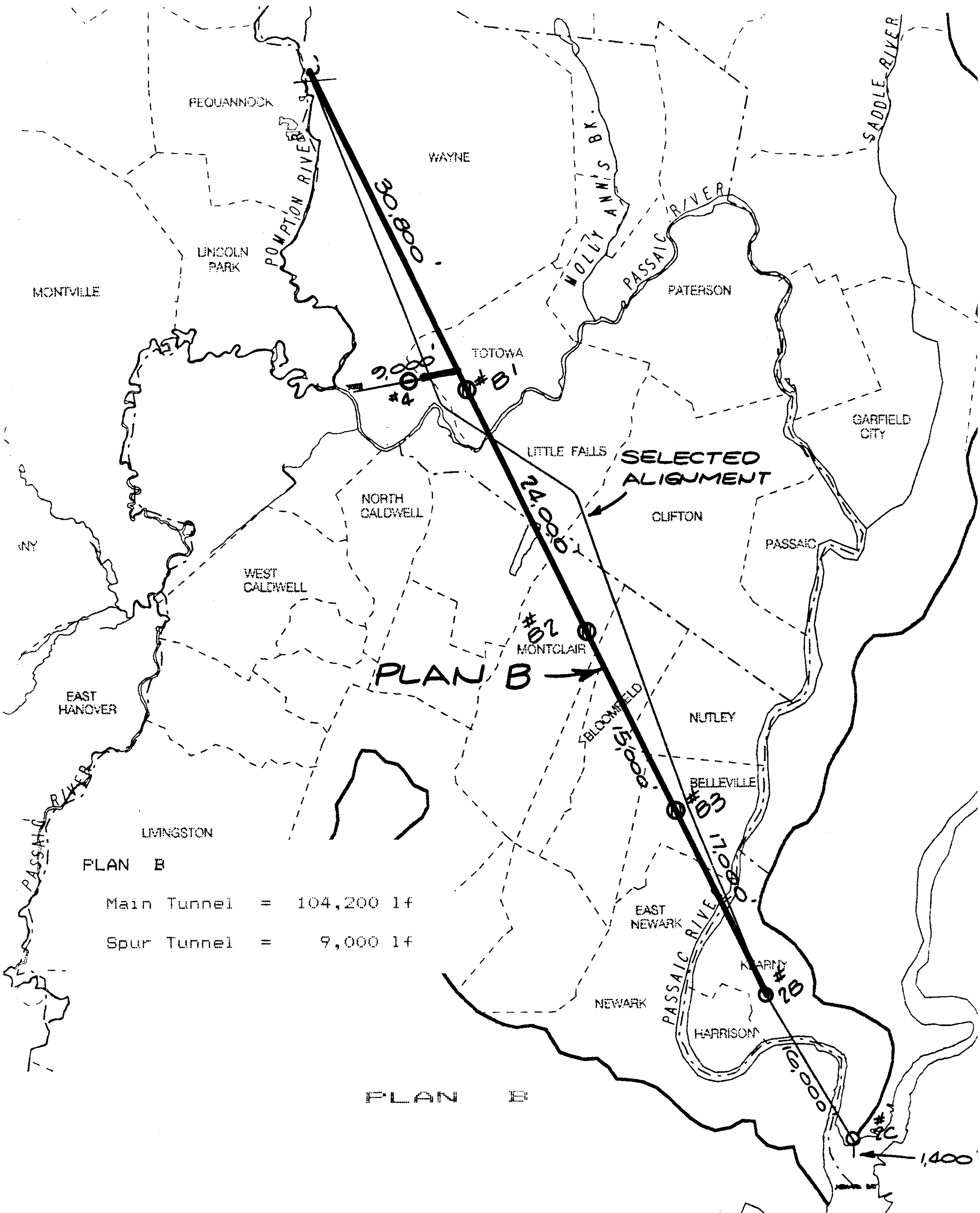

PEQUANNOCK
WAYNE
POMPTON RIVER
MOLLY ANN'S BK.
SADDLE RIVER
PASSAIC RIVER
LINCOLN PARK
MONTVILLE
PATERSON
TOTOWA
30,800'
9,000'
#4
#B1
GARFIELD CITY
LITTLE FALLS
SELECTED ALIGNMENT
NORTH CALDWELL
CLIFTON
24,000'
PASSAIC
WEST CALDWELL
#B2
MONTCLAIR
PLAN B
EAST HANOVER
BLOOMFIELD
NUTLEY
15,000'
BELLEVILLE
#B3
LIVINGSTON
17,000'
PLAN B
Main Tunnel = 104,200 lf
Spur Tunnel = 9,000 lf
EAST NEWARK
PASSAIC RIVER
KEARNY
#2B
NEWARK
HARRISON
16,000
#2C
1,400'
PLAN B

Figure F-4

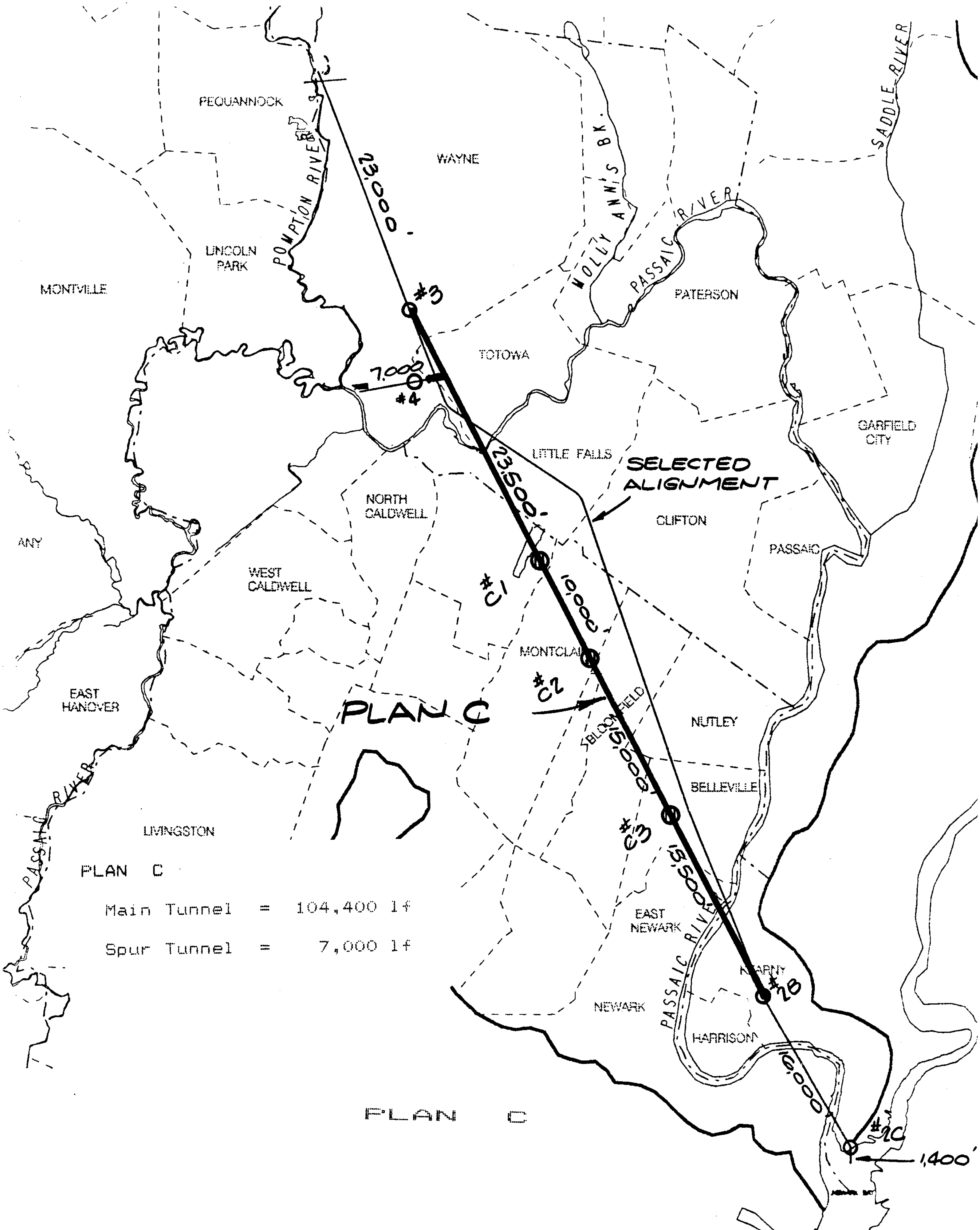

PEQUANNOCK
WAYNE
POMPTON RIVER
MOLLY ANN'S BK.
SADDLE RIVER
PASSAIC RIVER
LINCOLN PARK
MONTVILLE
PATERSON
TOTOWA
GARFIELD CITY
LITTLE FALLS
SELECTED ALIGNMENT
NORTH CALDWELL
CLIFTON
PASSAIC
ANY
WEST CALDWELL
MONTCLAI
NUTLEY
BELLEVILLE
EAST HANOVER
LIVINGSTON
EAST NEWARK
KEARNY
NEWARK
HARRISON
23,000'
#3
7,000'
#4
23,500'
#C1
10,000'
#C2
15,000'
#C3
13,500'
#2B
16,000
#2C
1,400'
PLAN C
PLAN C
Main Tunnel = 104,400 lf
Spur Tunnel = 7,000 lf
PLAN C

Figure F-5

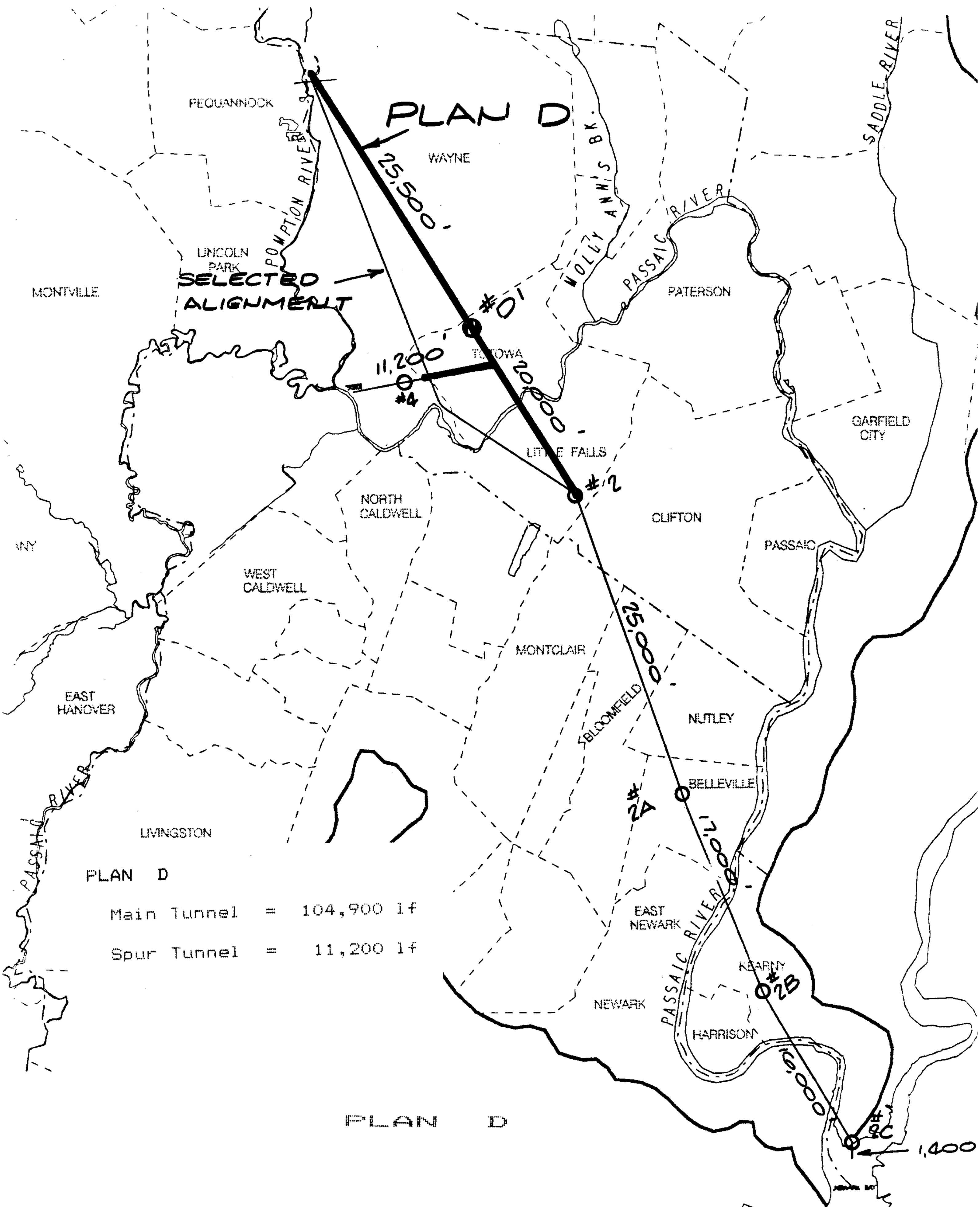

PLAN D
SELECTED ALIGNMENT
25,500'
#01
11,200'
#4
20,000'
#2
25,000'
#2A
17,000'
#2B
6,000'
1,400
PEQUANNOCK
WAYNE
POMPTON RIVER
MOLLY ANN'S BK.
PASSAIC RIVER
SADDLE RIVER
LINCOLN PARK
MONTVILLE
PATERSON
TOTOWA
GARFIELD CITY
LITTLE FALLS
NORTH CALDWELL
CLIFTON
PASSAIC
WEST CALDWELL
MONTCLAIR
EAST HANOVER
NUTLEY
BLOOMFIELD
BELLEVILLE
LIVINGSTON
EAST NEWARK
KEARNY
NEWARK
HARRISON
PLAN D
Main Tunnel = 104,900 lf
Spur Tunnel = 11,200 lf
PLAN D

Figure F-6

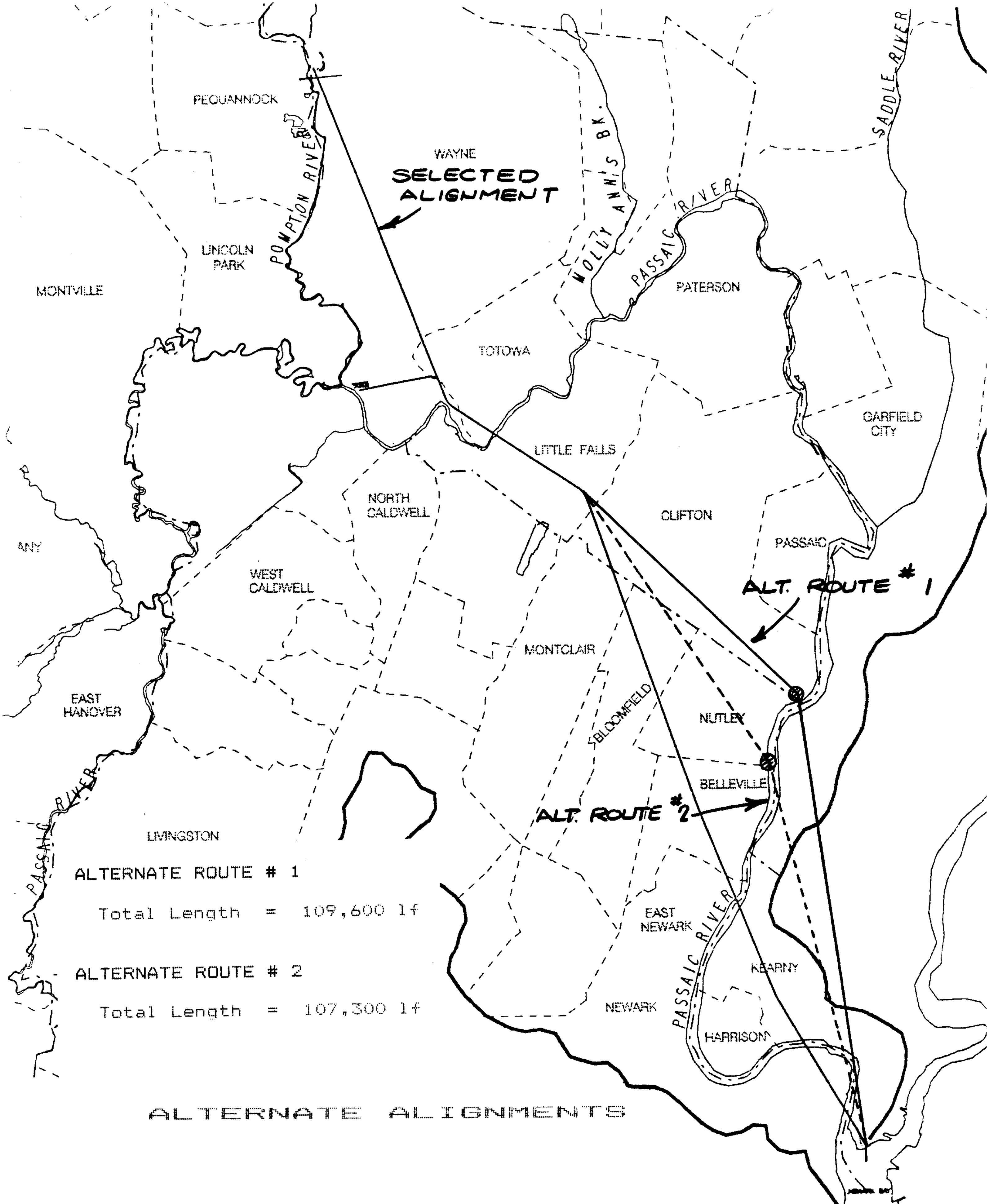

PEQUANNOCK
WAYNE
SELECTED ALIGNMENT
POMPTION RIVER
MOLLY ANN'S BK.
PASSAIC RIVER
SADDLE RIVER
LINCOLN PARK
MONTVILLE
PATERSON
TOTOWA
GARFIELD CITY
LITTLE FALLS
NORTH CALDWELL
CLIFTON
PASSAIC
WEST CALDWELL
ALT. ROUTE # 1
MONTCLAIR
EAST HANOVER
BLOOMFIELD
NUTLEY
BELLEVILLE
ALT. ROUTE # 2
LIVINGSTON
EAST NEWARK
KEARNY
NEWARK
HARRISON
ALTERNATE ROUTE # 1
Total Length = 109,600 lf
ALTERNATE ROUTE # 2
Total Length = 107,300 lf
ALTERNATE ALIGNMENTS

Figure F-7

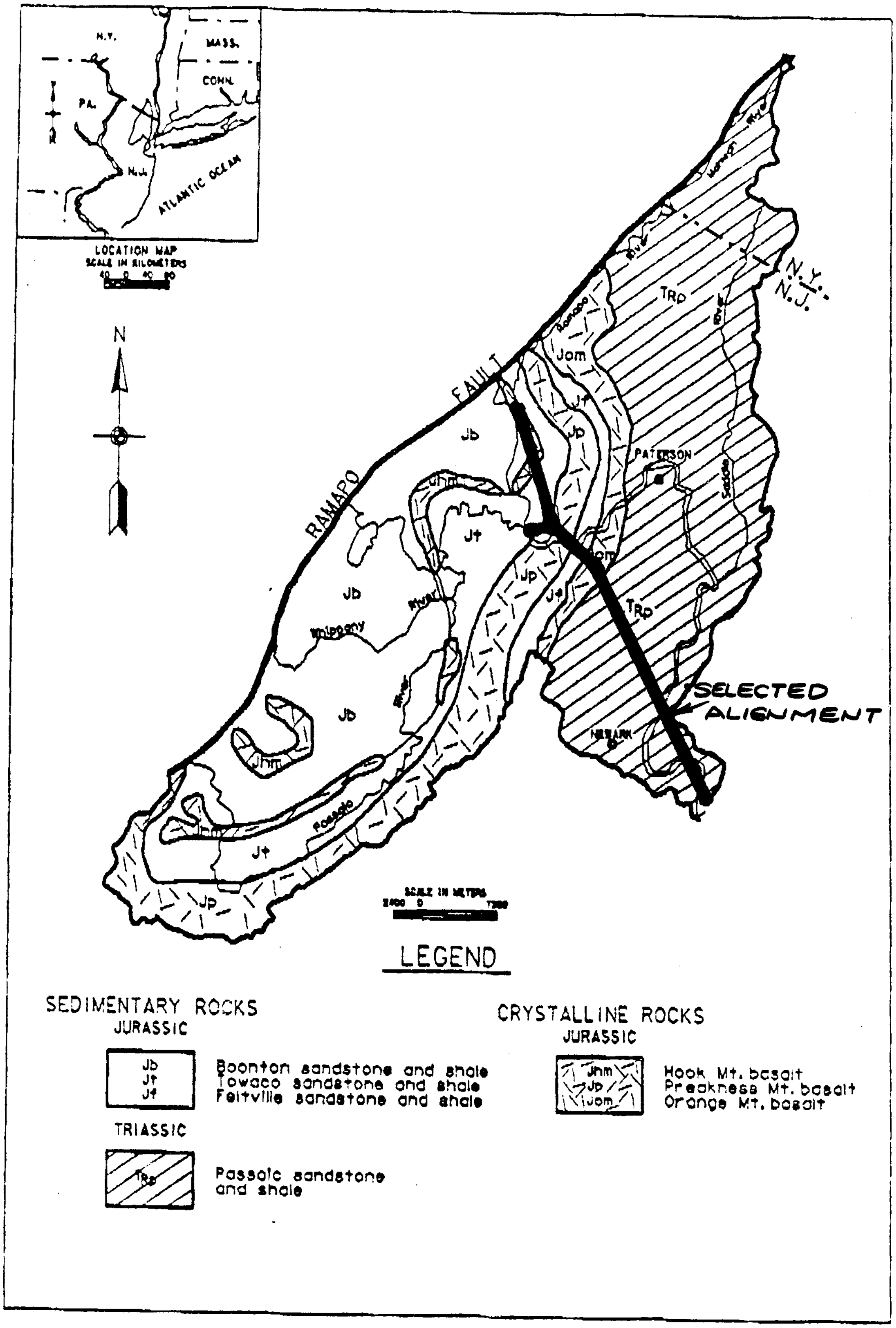

N.Y.
MASS.
CONN.
PA.
N.J.
ATLANTIC OCEAN
LOCATION MAP
SCALE IN KILOMETERS
40 0 40 80
N
RAMAPO FAULT
Jb
Jhm
Jt
Jp
Jom
TRp
PATERSON
NEWARK
N.Y.
N.J.
Whippany
River
Passaic
SELECTED ALIGNMENT
SCALE IN METERS
LEGEND
SEDIMENTARY ROCKS
JURASSIC
Jb
Jt
Jf
Boonton sandstone and shale
Towaco sandstone and shale
Feltville sandstone and shale
TRIASSIC
TRp
Passaic sandstone and shale
CRYSTALLINE ROCKS
JURASSIC
Jhm
Jp
Jom
Hook Mt. basalt
Preakness Mt. basalt
Orange Mt. basalt

Figure G-1

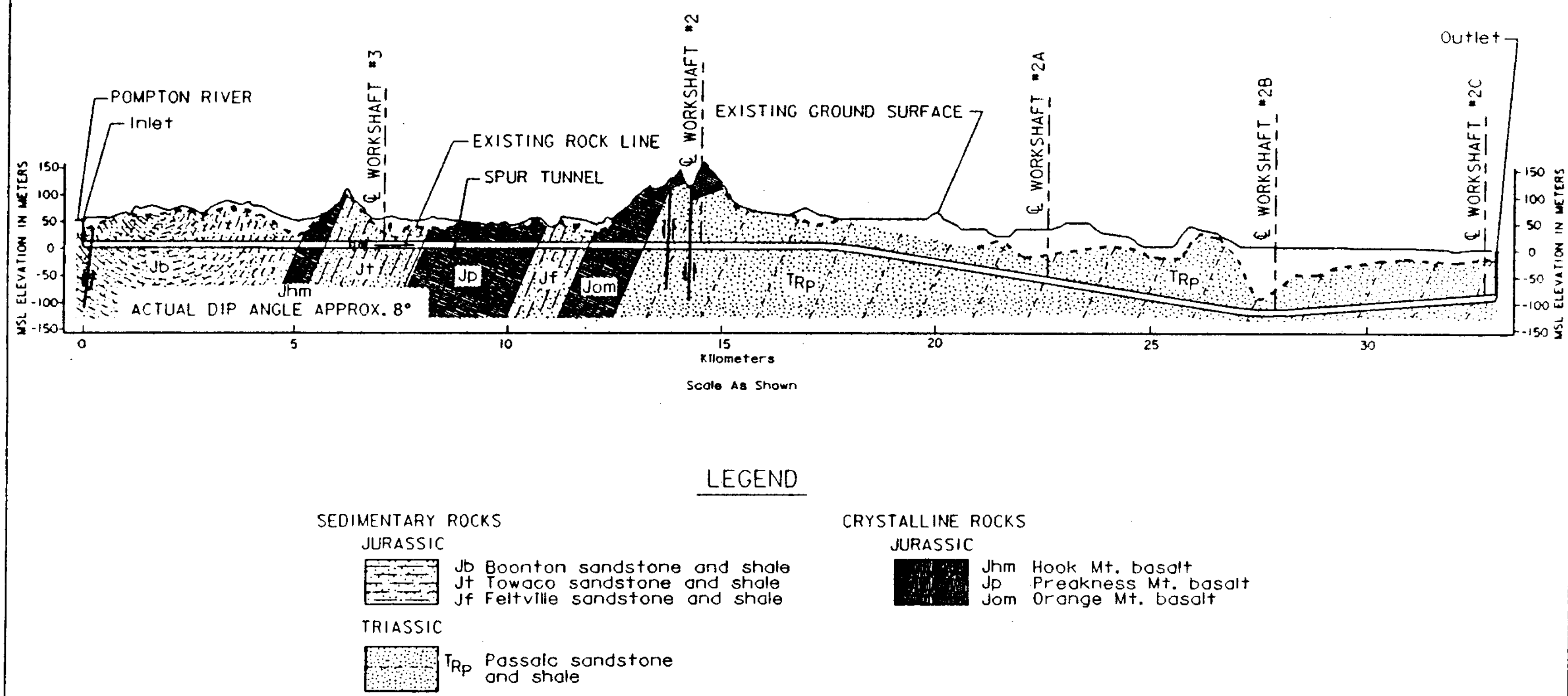
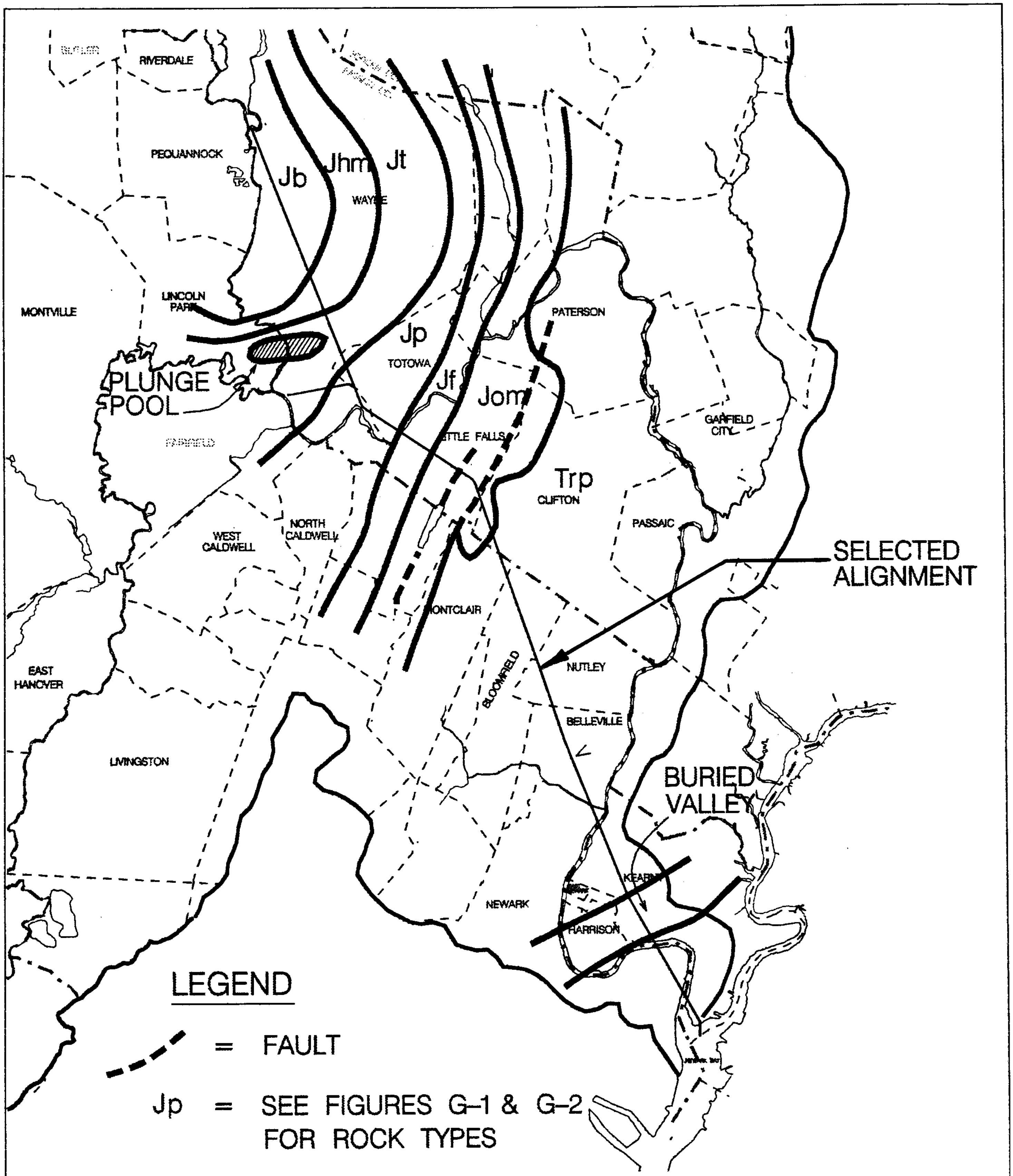

POMPTON RIVER
Inlet
℄ WORKSHAFT #3
EXISTING ROCK LINE
SPUR TUNNEL
℄ WORKSHAFT #2
EXISTING GROUND SURFACE
℄ WORKSHAFT #2A
℄ WORKSHAFT #2B
℄ WORKSHAFT #2C
Outlet
MSL ELEVATION IN METERS
150
100
50
0
-50
-100
-150
Jb
Jhm
Jt
Jp
Jf
Jom
TRp
ACTUAL DIP ANGLE APPROX. 8°
0
5
10
15
20
25
30
Kilometers
Scale As Shown
LEGEND
SEDIMENTARY ROCKS
JURASSIC
Jb Boonton sandstone and shale
Jt Towaco sandstone and shale
Jf Feltville sandstone and shale
TRIASSIC
TRp Passaic sandstone and shale
CRYSTALLINE ROCKS
JURASSIC
Jhm Hook Mt. basalt
Jp Preakness Mt. basalt
Jom Orange Mt. basalt

Figure G-2



LOCATIONS OF TOP – OF – ROCK DEPRESSIONS

keller.dgn

FIGURE G-3