THE RIDDLE OF MARS

THE PLANET

C. E. HOUSDEN

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BY

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WITH THREE COLOURED PLATES AND OTHER ILLUSTRATIONS

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PREFACE

THE planet Mars has a special fascination for the layman as well as for the astronomer, inasmuch as it is probably the only member of the solar system, our own Earth of course excluded, on which the existence of animal life is at all likely, as far as can be concluded from our present knowledge of our neighbour worlds.

Early in 1913 the writer had the privilege of reading, at a meeting of the British Astronomical Association, a short paper, printed in their Journal for March of that year, on 'Mars and its Markings,' in which some new points were advanced in support of Prof. Lowell's by now well-known views with regard to the artificial character of two of the minor markings, designated by him its canals and oases, to be seen on the planet's disc, by suggesting *inter alia* that water is probably transmitted along the canals by being pumped through pipes under pressure, and explaining why and where a single canal or a double canal would be needed.

A suggestion accepted by Mr. Lowell.

For the solution of an astronomical problem circumstantial evidence is all that is available, and certainty can never be attained from such evidence alone; nevertheless, if practically similar conclusions are arrived at by two independent methods of dealing with such evidence as is available, there must be much in favour of these conclusions being in the main correct.

Mr. Lowell's views with regard to the nature of Mars' canals and oases were mainly reached by direct observation. Over and over again, in his published works and memoirs on the planet, he insists on their regular behaviour and on their artificial look. Their rhythmic waxing and waning is frequently emphasised, and in 'Mars as the Abode of Life' he writes:—'Confronting the observer are lines and spots that but impress him the more, as his study goes on, with their non-natural look. So uncommonly regular are they, and on such a scale, as to raise suspicion whether they can by nature be regularly produced.'

The regularity, the character, and indeed the very existence of these minor markings are, however, questioned by some astronomers; an endeavour is therefore now made to solve the riddle of Mars (of what is possibly happening there) from quite a new direction, to wit: an analysis of, and deductions, based mainly on mundane irrigation experience, from, the extensive colour changes which have from time to time been noticed, even in small telescopes, in the main features of the martian disc, the existence of any minor markings being, to begin with, ignored as far as possible.

A confirmation of Mr. Lowell's theories and maps is, it will be found, the outcome of such an investigation. This result will, it is hoped, help towards the universal acceptance of the artificial nature of Mars' canals and oases and all that this implies.

C. E. H.

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THE RIDDLE OF MARS

CHAPTER I

COLOUR CHANGES ON MARS

WHEN Mars is viewed even through a moderate-sized telescope, three distinct colours can be clearly made out on its disc: These are:

(*a*) Two comparatively small circular patches of white at its poles;

(*b*) A broad band of ochre occupying very nearly the entire centre of the planet; and

(*c*) Two more or less connected narrower bands of blue-green lying between the white polar caps and the central ochre band.

The blue-green band in the southern hemisphere is wider and less disjointed than the one in the northern hemisphere.

The first change in these coloured areas was noticed by the eminent astronomer Sir William Herschel, who ascertained that the white at the polar caps waxed and waned with the martian seasons, increasing during the winter months of each polar hemisphere and decreasing during the summer months of the same hemisphere. From these changes it was inferred by him that the white colouring at the poles was due to snow which accumulated during the winter and was melted off with the advent of summer.

These annual changes have been since confirmed by many other observers, and it is now generally allowed that the explanation of the changes in Mars' polar caps advanced by Sir William is a correct one.

Further examination of the polar snows has shown many observers that, as they melt, the decreasing caps are bordered by a dark blue band which follows and narrows with the dwindling caps, and can thus be only water. That it is so is now generally allowed. This band, however, rapidly disappears, the areas originally occupied by it showing first dark brown and then fading out to ochre, leaving ultimately a small kernel of white bordered by a very narrow blue band in the centre of the vast ochre area thus exposed to view.

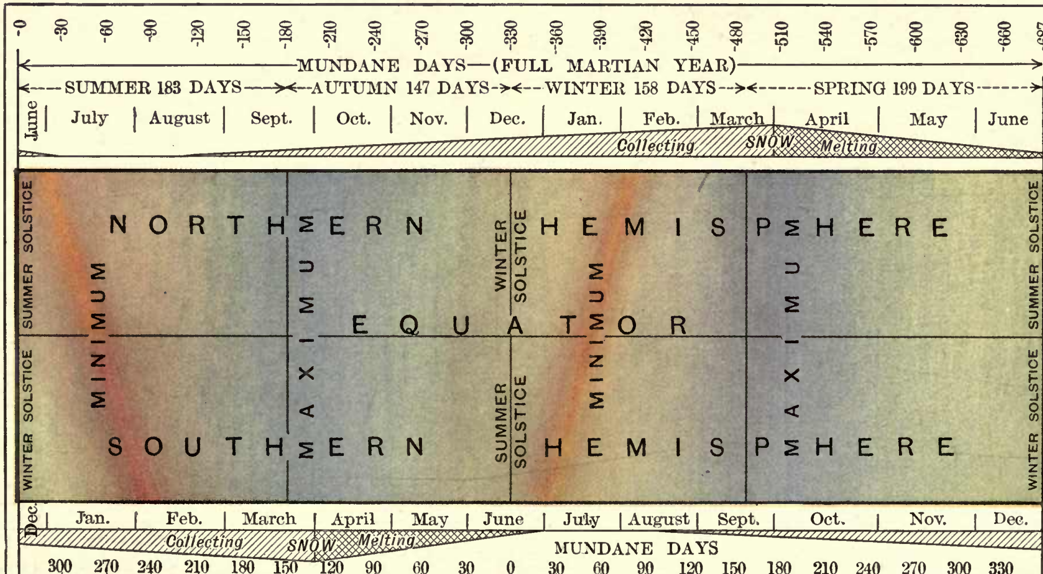


Plate I.—Diagram of Colour Changes on Mars During a Full Year

A martian month or so later the caps commence to re-form. More recent observations of Mars by Prof. Lowell have fixed the approximate dates at which the snow caps commence to form and commence to melt again, also the approximate dates at which they reach, and the time during which they remain at, their minima. These martian dates and time are about the middle of August, about the first of April, and from about the first of July to mid-August for each polar hemisphere.

The snow thus collects for about seven and a half martian months, is about three such months in nearly all melting off again, and does not either perceptibly increase or decrease during the remaining one and a half months.

Changes in the colour of the extensive blue-green areas were first observed by the gifted observer Schiaparelli, who also noticed that these changes were seasonal and that the blue-green waxed and waned twice in each martian year, somewhat as shown in Plate I.

The nature of the colour variations in these blue-green areas has, however, been more definitely established by Mr. Lowell's later observations of the planet, and his cartouches (graphic representations) of their waxing and waning more approximately fix the times and intensities of their colour changes during 30 mundane days before, and 150 mundane days after, the summer solstice of Mars' northern hemisphere.

These cartouches are given in detail in *Lowell Observatory Bulletin*, No. 12.

Plate I has been prepared by the author from a study of all observed colour changes, mainly recorded by Mr. Lowell, in the blue-green areas. It approximately illustrates for a whole martian year the rhythmic waxing and waning of the blue-green areas on Mars.

The plate also shows the annual changes in the polar caps.

The ochre-coloured areas on Mars, which do not change to any marked extent, are now generally admitted to be deserts.

The extensive blue-green areas are, it is further now admitted, not seas, as it was at one time supposed they were. Their colouring is accounted for by two rival theories: the one holds that they are what were once Mars' ocean basins, and that they are in consequence depressed areas now covered twice a year with vegetation; and the other that they are what on Earth would practically be permanently-frozen swamps.

Let us examine these rival theories in the light of observed facts.

As the polar caps, it is admitted, consist of snow, the temperature on Mars where this is melting must be over 0° C.

Suppose that the snow is melting during the summer of the southern hemisphere and that when this is the case the temperature at the equator of Mars is 20° C., then 20° C. will also on the same day be the winter temperature at the equator of the northern and colder hemisphere, and the temperature in this hemisphere will not fall to 0° C. until some considerable distance to the north of the equator. Thus summer and winter the temperature of a good deal more than half of the surface of Mars must be always well above freezing-point and permanently-frozen swamps in its temperate and equatorial regions an impossibility.

Again, Plate I shows the blue-green all over Mars to be at a minimum about mid-January and mid-July of the martian year and at a maximum about mid-April and mid-September, whereas if the colour changes were due to the freezing and unfreezing of swamps, the changes noticeable in the northern and southern hemispheres should be radically different. The blue-green areas are therefore, without reasonable doubt, mainly depressed areas covered with vegetation which waxes and wanes as shown in Plate I, the time from minimum to minimum being somewhat shorter in the warmer polar hemisphere in which the snow is at the time melting than in the opposite and at the time cooler one.

These differences in time from minimum to minimum in the two opposite polar hemispheres indicate that the sun exercises some influence on the growth of vegetation on Mars, notwithstanding the fact that this vegetation is, generally speaking, at much the same time, at a maximum or at a minimum all over Mars twice in each year.

On Earth, on the other hand, vegetation is, in each polar hemisphere, at a maximum during its summer months, and at a minimum during its winter months. The seasons of the maxima and minima of vegetation on Mars and on our Earth therefore differ to a considerable extent, and it is only reasonable to assume that their non-agreement is due to different causes being at work on the two planets, as we shall see later on is very probably the case.

For vegetation to wax and wane year in and year out, successive waterings, either natural or artificial, are needed. Before proceeding to a consideration of how the required waterings are probably applied to the soil, it will be advisable to form some conception in mundane units of the extensive areas which have to be so watered, and to briefly compare Mars and the Earth with each other—as far as is necessary for our purpose—also to try and ascertain whence the water required for the maintenance of the martian vegetation is probably obtained.

CHAPTER II

MARS AND THE EARTH COMPARED

THE diameter of Mars is a little more than half that of the Earth. The inclination of the equator of Mars to its orbit is almost exactly the same as that of the Earth. The seasons of the two planets are therefore practically similar, except that those on Mars are nearly twice as long as on our own Earth on account of its longer year. The martian day is about forty minutes longer than our own.

Mars and the Earth compare in points already referred to and in several other respects as shown in the statements below tabulated :

I. Proportionate Dimensions.	Mars.	Earth.
Diameter in miles . . .	4,220	7,920
Surface area in sq. miles . .	56,000,000	197,000,000
Force of gravity (g) at surface .	12	32
Albedo or portion of light reflected (Lowell) . . .	0·27	0·75
Mass	1	9
Atmospheric density	2½ lbs	30 lbs
II. Details of Orbits.		
Inclination of equator to orbit .	23° 13′	23° 27′
Length of year, mundane days . actual	686·98	365·26
	h. m. s.	h. m. s.
Period of rotation . . .	24 37 23	23 56 4

III. Surface Markings.

	Mars. (100 p.c.)	Earth. (28 p.c.)
Area of land surface in sq. miles	56,000,000	55,160,000
,, sea ,, ,, ,,	nil	141,840,000
,, blue-green or vegetation in sq. miles) . .	21,000,000	say 50,000,000
,, n. polar cap in sq. miles	7,000,000	30,000,000
,, s. ,, ,, ,, .	10,500,000	30,000,000

IV. Physical Features.

Heights of mountains, maximum	at most 3,000 feet, or say 0·5 miles	29,000 feet, or 5·5 miles.
Average depths of oceans, or what were on Mars once oceans, *i.e.* its extensive blue-green areas.	at most 1,500 feet, or say 0·25 miles	12,600 feet, or 2·4 miles.

It will be seen from the above that the surface of Mars is, as compared with the Earth, surprisingly flat.

V. Atmosphere.—It is now generally admitted that Mars is surrounded by an atmosphere probably similar in composition to that of the Earth; its amount, calculated from the planet's albedo (0·27) as compared with that of the Earth (0·75), is put by Mr. Lowell at $\frac{2}{9}$ or $\frac{1}{4\cdot5}$ of that of our own Earth over each square unit of surface.[1] Assuming, however, that the original quantity of air on each planet was as that planet's mass, or as 1 (Mars) to 9 (Earth), the amount of the air on Mars should be $\frac{1}{2\cdot7}$ of

[1] Note 11 to *Mars as the Abode of Life*.

that on Earth. The reduction in amount from $\frac{1}{2 \cdot 7}$ to $\frac{1}{4 \cdot 5}$ is probably due to the relatively greater loss of air Mars has sustained from parting, owing to its smaller mass, more quickly with a portion of its air envelope.

For this same reason the martian atmosphere perhaps contains relatively more oxygen than does our own.

If the amounts of free hydrogen and free oxygen originally owned by the Earth and Mars were in proportion to their respective masses, there must have been nine times as much hydrogen and nine times as much oxygen on Earth as on Mars. The amount of water formed by the combination of all the hydrogen with one-half the oxygen should have been also nine times more on Earth than on Mars. The quantity of water at present stored in the mundane ocean basins is about $141,840,000 \times 2 \cdot 4 = 340,500,000$ cubic miles, whereas the amount of water originally owned by Mars, judging from the quantity which could have been stored in its old ocean beds, could not, unless a large portion of it has found a lodgment somewhere in the planet's interior, have at any time much exceeded $21,000,000 \times \frac{1}{4} = 5,250,000$ cubic miles, or only about one sixty-fourth part of the amount at present held by the Earth's ocean basins, instead of at least one-ninth as, on the above supposition, it should have been. This large deficiency would appear to point to a proportionately larger escape of hydrogen from the planet in its very early evolutionary stage, and, therefore, to a relatively greater supply of oxygen in its present-day atmosphere.

What this might mean to animal life on Mars is self-evident. By taking up oxygen with them the three passengers of the balloon 'Icare' were able to ascend to a height of 32,000 feet, 'without suffering any particular discomfort.'

Lungs to suit the actual amount of oxygen in Mars' air have, however, doubtless been evolved if they are needed on the planet.

VI. Water Vapour.—Water vapour has been proved, by spectograms obtained at the Lowell observatory, by the regular formation and melting of Mars' polar caps, and in many other ways, to be present in the martian air; this vapour is clearly due to evaporation from a watered surface, or from vegetation.

Owing, however, to the present great thinness of Mars' air, the water vapour suspended in it cannot, at any rate in the equatorial and temperate zones, now condense into rain clouds (nimbus) (the yellow clouds often seen and also photographed on Mars in these regions being almost certainly due to fine 'desert dust' blown into its air). There can consequently be but little precipitation of water on Mars, and that mainly in the form of dew, except in its polar regions, where snow, sleet and hail storms perhaps occur, but where more probably, as in the case of our own poles, 'flakes of snow are not formed at the low temperature there met with, but precipitation is in the form of ice spicules. The finest glittering ice needles often fill the air even on clear days and in calm weather, and, gradually descending to the surface, slowly add to the depth of snow on the ground.'

A deposit of hoar frost presupposes a previous deposit of dew.

Water vapour in an atmosphere is by itself (even when, as on Earth, its presence to saturation is evidenced by clouds drifting past overhead without the precipitation of rain) of no great assistance to vegetable life, as parched fields under cloudy skies have demonstrated in many an Indian famine. Witness also the dire effects, in some cases, of the English summer of 1913, a cloudy one with a small rainfall.

VII. Temperature.—The mean temperature of the Earth is about 61° F. Were it not for the Earth's high albedo, which shows that a considerable portion of the light and heat reaching it are reflected, from clouds and dust suspended in its atmosphere, back into space, it would be considerably greater.

The temperature on Mars is, as has already been shown, always well over 0° C. (32° F.) for considerably more than half the planet's surface—really about five-sixths. Prof. Lowell has, moreover, mathematically ascertained[1] that the planet's mean temperature is about 48° F., or 10° C.

During the long winter night of a polar cap the cold on a part of Mars is doubtless very intense; but this will have no marked effect on the temperature of the greater part of the planet, which must, between snow caps, be always above 0° C. (32° F.), except most probably during the night, when there is very likely a perhaps heavy deposit of hoar frost, as is the case in parts of our own Earth, where nevertheless vegetation is not killed by it owing to the day temperature again regularly rising above freezing-point.

48° F., or thereabouts, may therefore be taken with confidence as very near the true mean temperature of Mars, at least five-sixths of whose surface temperature is always well above 32° F., and water on the planet thus not everywhere normally in the condition of ice, but mostly in

[1] Note 12 to *Mars as the Abode of Life.*

that of water which can flow and be utilized in the production of vegetation.

VIII. Amount of Water required for the Maintenance of Vegetation.—Mundane experience has shown that, to secure the growth of crops by irrigation from flowing water, a very large supply is needed, the usual provision made in the preparation of projects for the irrigation of dry localities being in the neighbourhood of what is known as a 4 acre feet allowance; that is to say, a sufficient amount of water has to be arranged for to allow of each acre to be irrigated being covered by successive waterings during six of our months to a depth of 4 feet. A covering of 48 inches during six months is equivalent to an annual rainfall of 96 inches. Crops are, however, raised on Earth, and vegetation is fairly plentiful, where the annual rainfall is in the neighbourhood of 24 inches. Water can thus be made to go much further if it can be sprinkled on to the land to be irrigated, than if it is merely allowed to flow over it.

Indeed, to judge from an article in the *Nineteenth Century* for June, 1913, by William Macdonald, on 'A Rainless Wheat,' much has been done on Earth towards securing good crops in localities where the annual rainfall is under 15 inches by the adoption of a system of dry-farming.

Dry-farming consists mainly in the provision by deep ploughing of moisture-saving fallows and of deep sowing therein. These fallows can be maintained for periods of three months, six months, or a year, and must be kept constantly tilled to prevent the formation of a soil crust, which would result in the moisture, derived at intervals from a scanty rainfall, evaporating before it could sink into the soil.

As crops can, by such a system, be successfully raised on our own Earth from a fitful annual rainfall of under 15 inches, a smaller amount of water, say 6 inches in each six months, would doubtless suffice, if the rainfall could be regulated and the showers turned on when most needed, and not when they are practically of not much use.

It may therefore be allowed, bearing in mind Mars' colder climate, the consequent slower growth of its vegetation, and, therefore, a smaller demand for water for its maintenance, that a water covering of 9 inches in six martian months, somewhat less than a mundane year, could very probably be made to suffice for the maintenance of vegetable life on Mars, where water is admittedly very scarce and desert conditions mainly prevail, provided that a system analogous to dry-farming is in use and the water can be applied to the land in the form of 'a regulated artificial rain,' by being distributed over it exactly when and where required through sprinklers of some kind. Whether sufficient water to meet even this small requirement is likely to be available on Mars will have, in due course, to be taken into consideration.

CHAPTER III

FLOW OF WATER ON MARS

THE polar cap in Mars' southern hemisphere must, at its maximum, be a vast snowfield, as its average diameter is then about 3,600 miles and the maximum area covered by it about 10,500,000 square miles.

The whole cap (area 10,500,000 square miles), however, practically all melts off in about three martian months, or say 15,000,000 seconds, or at an average rate of $\frac{105}{150} = 0{\cdot}70$ square miles per second.

Taking the average depth of water available from the melting of the snow at half a foot over the cap's entire area, due to a 5 feet depth of snow (and a greater depth, owing to the rapidity with which it melts, could not well be calculated on), the rate of flow during the time the cap is melting would be a continuous one of $\frac{1}{2} \times 27{,}878{,}000 \times 0{\cdot}70$ = say, 10,000,000 cubic feet per second, or, in its usual abbreviation, 10,000,000 cusecs.

The water from the melting cap cannot drain into a neighbouring sea as it does on Earth, but must flow away overland to the so-called seas (depressed areas) of Mars' southern hemisphere.

With the escaping water headed up to a depth of 2 feet, and with a velocity of flow of 3 feet per second, the combined width of flow would have to be about 1,700,000 feet, or say 350 miles. To allow of a 3 feet velocity being generated we should require on Mars (see calculations in the Appendix) a fall in the water surface of about 1 in 300, or say, to be on the safe side, a fall of 20 feet per mile (1 in 264). As the least distance from the edge of the snow cap (about latitude 50°) to the centre of the southern seas (about latitude 10°) would be nearly 1,600 miles, the total fall needed in this distance would be $1{,}600 \times 20 = 32{,}000$ feet. No such fall is likely to be available in Mars.

With the water headed up to a depth of 4 feet, the velocity of flow could be reduced to $1\frac{1}{2}$ feet per second, requiring on Mars for its generation (see Appendix) a slope in the water surface of 1 in 3,600, representing a total fall of $\frac{32{,}000}{12} = 2{,}700$ feet. Such a fall could probably be obtained on Mars, but certainly not in every direction.

With a depth of 2 feet and a water surface slope of 1 in 3,600, the velocity generated on Mars would be 0·84 feet per second, and we should need a series of channels having a combined width of

$$\frac{10{,}000{,}000}{2 \times 0{\cdot}84} = \text{say } 6{,}000{,}000 \text{ feet or about } 1{,}200$$

miles.

To provide artificial carriage in open channels of low depth and low velocity for such a large discharge as 10,000,000 cusecs would be a matter of considerable difficulty; the water set free on the first melting of the southern polar cap must therefore mainly find a natural escape through very flat existing openings having a total combined width of either about 1,200 miles and a 2 feet depth through which the water flows with a velocity of 0·84 feet per second, or a combined width of about 350 miles with a depth of 4 feet and a rate of flow of 1½ feet per second, or something in the neighbourhood of these limits.

In other words, there must be great floods flowing over extensive plains near Mars' south polar cap during the whole time its snow is melting, the flood waters mainly finding an escape through the two large openings (see any map or globe of Mars) to the east and west of Hellas, *i.e.* the Mare Hadriacum and the Hellespontus, and in part through other small openings in the chain of 'Islands' to the north of the polar cap.

The water so escaping would, if not interfered with, find a lodgment at the lowest points in the seas (depressed areas) lying to the north of the above referred to island chain, viz. the Mare Erythræum, the Mare Cimmerium, the Mare Sirenum, etc., and there show as large lakes.

What however does the telescope reveal to be the appearance of Mars to the north of its south polar cap at the time this cap commences to melt? This portion of Mars shows dark blue-green throughout (Plate I), evidently due to vegetation, at the time at nearly full growth all over Mars, produced by water drawn or coming from some source other than the melting polar cap. There ought, however, to be some evidence of the flood waters flowing through the existing vegetation and of their collecting into large lakes. Let us see if we can find any recorded markings in this region of Mars to assist us. Several small circular spots (Mr. Lowell's oases) have in large telescopes been seen in the dark blue-green. *Lowell Observatory Bulletin*, No. 40, also states that these dark blue-green areas were, at the time the observations recorded therein were made, *i.e.* shortly after the south polar snow commenced to melt, traversed by lines 'which appeared uncommonly broad, ill-defined, and perhaps partially formed.'

What we may gather from these observed markings is that the broad ill-defined streaks then seen traversing the blue-green areas mark, in the region under observation, the general directions followed by the escaping floods flowing through vast plains of existing vegetation, and that the small spots mark the lowest points in the seas where the floods should eventually collect and show as large lakes, were they permitted to do so to any considerable extent.

The water flowing down the escape channels is therefore somehow spirited away in large quantities before it has time to collect into such lakes. This could have, engineering experience suggests, been effected, as the floods moderated and showed a tendency to collect into low-lying ground, by pumping the water away from where it was collecting, and would be useless, and, moreover, liable to escape into the air by evaporation, to where it could be usefully utilized. This would naturally be in the irrigation of crops or vegetation, at the time nearly at full growth all over Mars.

The maximum diameter and area of the polar cap in Mars' northern hemisphere are about 3,100 miles and 7,000,000 square miles respectively.

As the cap melts it is, like the southern one, seen to be bordered by a dark blue band, a northern flood, which accompanies the dwindling cap and decreases in width as the latter grows smaller, until both are obscured by the mist or haze which annually forms, about May to June, over Mars' northern polar cap. This mist is, in Mr. Lowell's opinion, due to evaporation from water set free by the melting of the polar snows which cannot be carried off as fast as it is available. This opinion, combined with a study of Mr. Lowell's maps of Mars' northern hemisphere when the cap is at a minimum, suggests that the water from the melting cap spreads out over a more or less level plain, having, however, a slight general fall southwards.

The snow cap when at its maximum has an outer boundary of about 9,700 miles, through many continuous gaps in which the water from the melting snows apparently escapes in all directions with a small depth and low velocity, and partly gives rise to something in the nature of a large series of swamps mostly situated near to, or at no great distance from, the melting polar cap.

To make use of the water so locally collected or collecting, it would be necessary, as in the case of the southern hemisphere, to pump it from where it is collecting to where vegetation is at the time in full growth all over Mars.

That the water is so pumped will be, it is hoped, demonstrated in the succeeding chapters.

CHAPTER IV

FLOWING WATER—HOW UTILIZED

It has been remarked at the end of Chapter III that to utilize usefully the large quantity of water set free by the melting of both Mars' polar caps, it would be necessary to use it for the irrigation of vegetation at the time at very near full growth in all Mars' blue-green areas. To effect this, a small portion of the floods, working north from Mars' south polar cap, could very likely be artificially diverted along their margins and utilized for the said purpose on a part of the blue-green areas of its southern hemisphere. The greater portion of the flood waters could not, however, be so dealt with, and would pass on to low points in the Mare Erythræum, the Mare Sirenum, etc., and would have to be pumped therefrom for the irrigation of the remaining portion of the blue-green areas in this hemisphere, as well as of all the extensive blue-green areas in the northern hemisphere, as no water would at

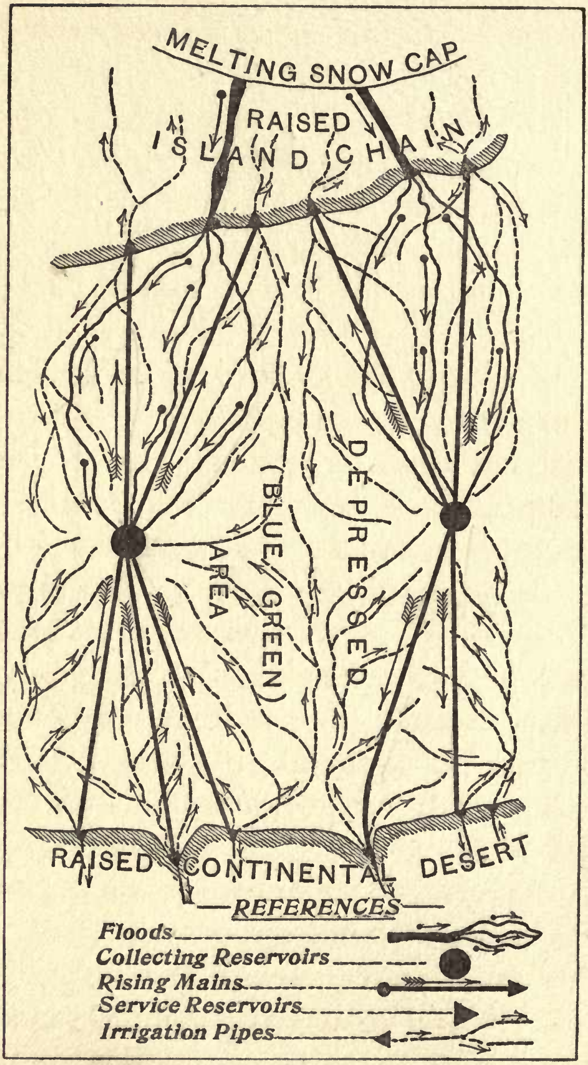


PLATE II.—ILLUSTRATING THE IRRIGATION OF A DEPRESSED AREA IN MARS' SOUTHERN HEMISPHERE the time be available for this purpose from the northern polar cap, which is then snow-bound (Plate I).

The simplest, and in the long run perhaps the most economical, way in which this could be effected under similar conditions on our own Earth, would be to pump the water through water-tight pipes or conduits from the low points at which it is collecting up to service or distribution reservoirs situated on convenient high points within or, preferably, on the margins of the areas to be irrigated, whence it could be carried in the required directions through water-tight pipes under a static head, from which pipes and from smaller pipes branching therefrom, and from still smaller pipes branching from these branch pipes, the water could be distributed all over the areas needing irrigation, in the form of 'regulated artificial rain showers,' through mechanical sprinklers worked under a pressure head.

The distribution of water to a depressed area of Mars' southern hemisphere being somewhat as illustrated in Plate II.

The actual continuous flow from Mars' south polar cap is probably a large one—under the assumed conditions, 10,000,000 cusecs—and would need a large number of pipes, taking off, however, from a large number of distribution centres, to allow of the available supply being even only lifted from collecting to service (distribution) reservoirs.

The diameter of each pipe would further be limited by the horse-power which could be economically developed at each pumping station along it, and could not therefore be very great.

If the pipes are buried underground, the only evidence of the direction followed by the water-conveying pipes (rising mains) would be the pumping stations, many miles apart, on them.

The distribution pipes, under static pressure, leading from the service reservoirs would not show at all.

Assuming, so as to have something definite to work on, that each 'rising main' has a diameter of 6 feet, and that the rate of flow through it is Mr. Lowell's ascertained rate of flow from north to south in the martian canals, viz. 2·1 miles per hour of 3·1 feet per second, the discharging capacity of each pipe would, as the area of a 6 feet diameter circle is 29·6 square feet, be $29{\cdot}6 \times 3{\cdot}1 = 90$ cusecs. As the continuous flow to be arranged for is 10,000,000 cusecs we should need $\frac{10{,}000{,}000}{90}$ = say, 120,000 such pipes for the purpose.

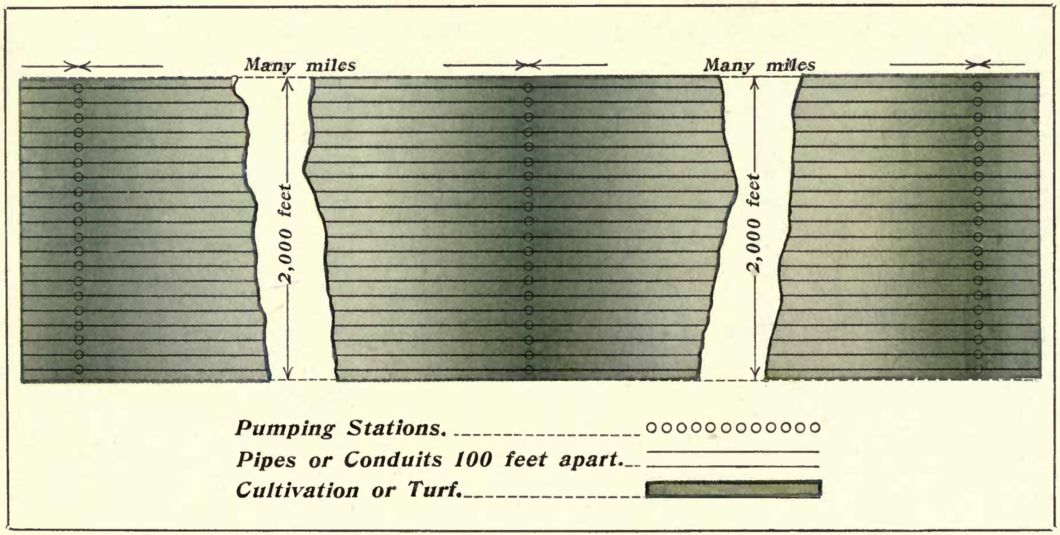


PLATE III.—PART PLAN OF SMALL MARTIAN CANAL CONSISTING OF TWENTY PIPES OR CONDUITS

These pipes could be grouped together according to the quantity of water to be raised to each service (distribution) reservoir.

Twenty pipes placed parallel to each other and say 100 feet apart, so as to allow of room for the pumping stations needed on each one, would, if laid in turfed banks and cuttings (so as to allow of these large pipes being graded), or if from any other cause (such as the irrigation for local food supplies of the land lying immediately above them) the line of pipes was rendered visible, show somewhat as illustrated in Plate III. That is to say, the line of pipes, if viewed from afar, would have very much the appearance of the streaks to be seen on Mars and designated its 'Canals,' inasmuch as it would show as a straight, very long, very narrow, and uniformly wide continuous shading.

Through such a 'Canal' $100 \times 20 = 2{,}000$ feet wide, $90 \times 20 = 1{,}800$ cusecs could be continuously pumped.

With a thousand pipes so arranged, the flow could be increased to a continuous one of 90,000 cusecs, and the width of the 'Canal' would now be 100,000 feet or close on 20 miles.

Now as such streaks, in some cases over 2,000 miles long and on the average about 10 miles in width, have been mapped as traversing, in straight lines, both the ochre and blue-green area of Mars in all directions, it is only a reasonable inference that they are due to a somewhat similar cause, and that they mark the directions in which water is being pumped through groups of parallel pipes from generally low-lying to higher points on the planet.

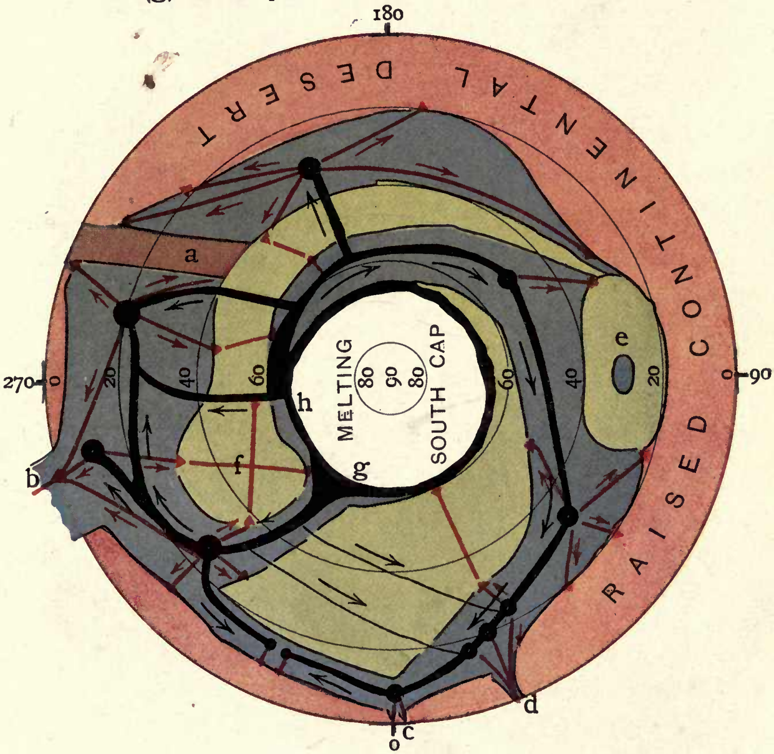
Such streaks do not show until some considerable time after the polar snows commence to melt, and are therefore other than the broad ill-defined ones, above referred to, which indicate the directions followed by the floods from the south polar cap.

Assuming that the 'Canals' indicate that water is being so pumped on Mars, we may proceed to try and form some conception of how the water-distribution system of which they form a part is possibly worked, when water from the melting snow caps is available; the 'Canals' being thus equivalent to what on earth are designated 'rising mains.'

The actual flow of water from the melting south polar cap and the rising mains and service reservoirs required for its distribution being probably somewhat as shown in Plate IV.

As the average width of the seas in the southern hemisphere is about 1,200 miles, the average distance from their centres to their north

(a) Hesperia (b) Syrtis Major (c) Sabaeus Sinus
(d) Margaritifer Sinus (e) Thaumasia (f) Hellas
(g) Hellespontus (h) Mare Hadriacum



Floods flowing through Crops.

Collecting Reservoirs.

Rising Mains.

Distribution Reservoirs.

Plate IV.—South Polar Hemisphere of Mars, showing the Actual Probable Distribution of Water to its Low-lying Areas on the Melting of its Snow Cap

and south margins cannot be much over 600 miles. The 'Canals' therein, however, would not necessarily proceed to the nearest points on their margins, but to some more distant and probably more convenient points thereon, as shown in Plates II and IV. The average length of the 'Canals' (rising mains) in these seas may, therefore, be taken at 1,200 miles each from centre to margin.

The water raised to convenient points on the northern margins of these southern seas would not only be needed for the irrigation of, say, half the area covered by them and the south island chain, but a fair portion of it, about one-half, would have to be pumped right across the intervening desert tract for the irrigation of the blue-green areas of the northern hemisphere, whose total area is somewhat less than a moiety of those in the southern hemisphere. To allow of this being done, we should need a number of 'Canals' crossing the central martian desert, and connecting the extensive blue-green areas of Mars' southern and northern hemispheres one with another.

These 'Canals' would have an average length of about 2,000 miles each.

The lengths of the 'Canals' crossing the northern blue-green areas may be put at about 1,200 miles.

The average length of each of the separate sections through which water would have to be pumped from collecting to service reservoirs would thus, at the most, be $\frac{1}{4}$ (1,200 + 1,200 + 2,000 + 1,200) = 1,400 miles.

Six months later, on the melting of the northern cap, water would have to be similarly conveyed across the central desert from north to south. The amount so available would perhaps, as the maximum area covered by the northern cap is 7,000,000 square miles, be a continuous flow of $\frac{7}{10} \times 10{,}000{,}000 = 7{,}000{,}000$ cusecs. This is on the supposition that the full amount available could be brought into use.

If, out of the 10,000,000 cusecs available from the southern polar cap, we assume that 7,000,000 cusecs will suffice for the irrigation of the blue-green areas in the southern hemisphere and 3,000,000 cusecs for that of the northern blue-green areas, the amount available for transmission from north to south will be 7,000,000 − 3,000,000 = 4,000,000 cusecs, or 1,000,000 cusecs more than from south to north; but another 3,000,000 cusecs would still be needed for the irrigation of the southern seas. This point is taken up later on.

If the intervening desert was a level plain or only undulated slightly, the pumping stations

D

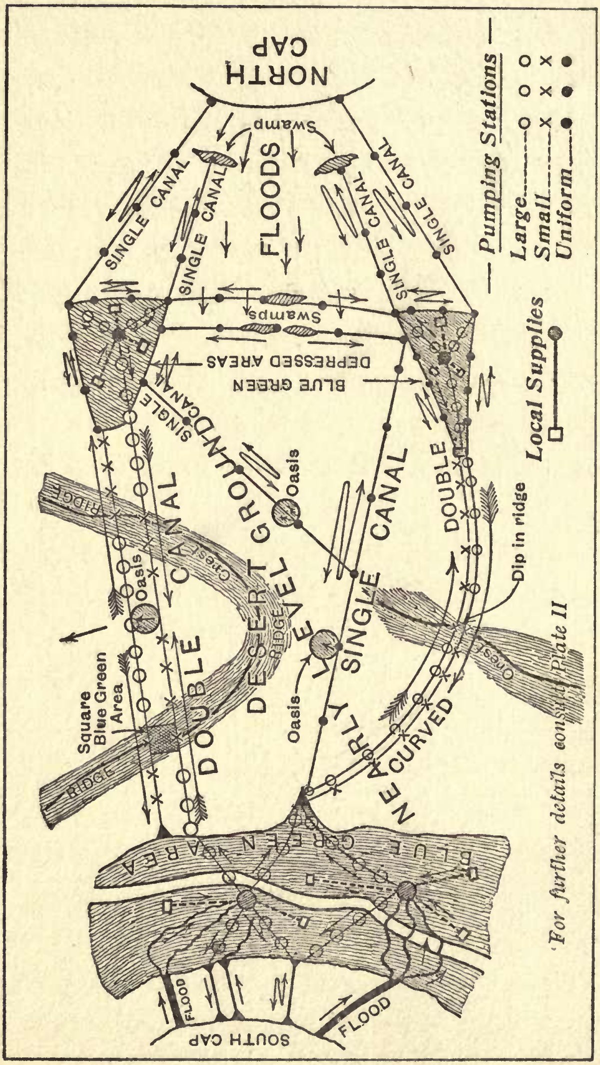


Plate V.—Plan Illustrating the Transport of Water Across Mars needed along the 'Canals' would be much the same distance apart and of much the same power, and water could be pumped from south to north, or north to south, through a single 'Canal,' by simply reversing the direction of flow; even if it was necessary to pick up *en route* a small blue-green area (an 'Oasis') situated in the intervening desert tract, a single line of pipes ('Canal') carried past or through the higher end of the 'Oasis,' from which the water required for its irrigation could be distributed by gravitation, would suffice, and the flow would be somewhat as illustrated in Plate V, 'Single Canals.'

[It may be here remarked that in Mars' northern hemisphere the water would most probably have to be, in the first instance, pumped from collecting points (swamps) outside the depressed blue-green areas of this hemisphere (the chief of which are the Mare Acidalium, the Propontis, and the Wedge of Casius) to service reservoirs on their margins, and not entirely from collecting points at the lowest points of these areas, as is the case in the southern seas.

All the three areas above-mentioned are widely separated from one another; and to allow of the flood water, which would otherwise escape through the gaps between them, being conveyed to them,

D 2

we should need, in addition to any direct 'Canals,' two parallel 'Canals' connecting each area with its neighbour, which could intercept the portion of the flood water flowing between them southwards from the melting north polar cap and carry it to these areas, as is illustrated in the northern end of Plate V; water caught by the southern canal passing over or under the northern one.

In this respect it will be seen that the northern hemisphere of Mars must differ materially from the southern one. In the southern one the water mainly gravitates a long distance to the lowest points of the blue-green areas, and is thence pumped up; in the northern hemisphere pumping has, to begin with, to be resorted to at no great distance from the polar cap and from swamps outside of and to the north of the main blue-green areas or lying between them.]

A double set of pipes would, however, be needed, if the ground over which water has to be pumped is far from level. Appreciable intervening heights would have to be surmounted, and a separate line of pipes with a different set of pumping stations—powerful ones on the up-grades and smaller ones on the down-grades—provided for the south to north flow and the north to south one, the directions of flow being somewhat as shown in the 'Double Canals' illustrated in the Plate above referred to—No. V; the 'Canal' carrying the north to south flow being probably the wider one of the 'Double.'

In Mr. Lowell's and other maps of Mars are shown many 'Canals,' both single and double, either directly connecting the extensive blue-green areas in the two polar hemispheres together, or more frequently picking up on the way a small blue-green area; and, strange to say, in many instances a 'Double Canal,' with one 'Canal' wider than the other, is used for the latter purpose with, in some cases, the small blue-green area situated exactly between the twin 'Canals.' Two different kinds of blue-green areas are, according to Mr. Lowell's maps, so picked up—small dark, round spots (the 'Oases' of Mars) and larger square areas of a lighter blue-green, as shown in Plate V.

From such an arrangement of pipes ('Canals') being necessary, it would appear that Mars' desert 'Oases' are situated in valleys, and probably mark the sites of desert water supplies, as well as the sites of present centres of population—in other words, cities and towns and their surroundings—to which the produce of the crops raised in the extensive blue-green areas of Mars is conveyed by some method of transport running along the 'Canals' which serve them, and that the square lighter-coloured areas mainly situated at 'Double Canal' crossings are relatively small patches of cultivation situated on an intervening height.

The spots ('Oases') in the extensive blue-green areas, on the other hand, probably mark points at which water is collected, and thus differ to some extent in character from the desert 'Oases.'

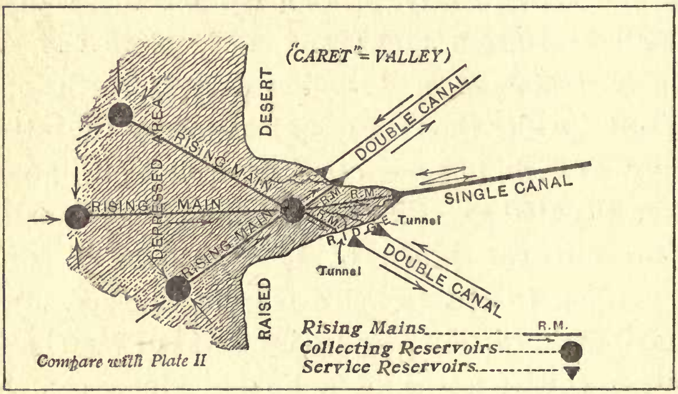


FIG. 1.—DETAILS OF FLOW THROUGH A 'CARET' ON MARS

The rise from the centre of an extensive depressed blue-green area to the raised central desert is probably negotiated through a valley leading therefrom, as shown in the sketch above (Fig. 1).

Such markings on Mars are designated by Mr. Lowell its 'Carets.'

A possible solution of the flow of water from Mars' polar caps is thus arrived at. In its first rush from the melting caps the water is carried forward by gravitation and comes to rest at low-lying points on the planet, to be thence pumped up to high level service reservoirs through the martian 'Canals,' which thus correspond to what on Earth are known as 'rising mains.'

From these service reservoirs the water is mainly distributed to the lands to be irrigated by gravitation through pipes under static pressure, but may be also, in some cases, perhaps distributed through open channels.

It remains to be seen whether the water available from the melting caps is likely to suffice for the full irrigation of all Mars' blue-green areas.

CHAPTER V

WATER FROM POLAR CAPS INSUFFICIENT

A GOOD portion of the water available from a melting polar snow cap would, on its being used for irrigation, be lost by sinking into the soil and entering into chemical combination and also in the production of vegetation, and would not in consequence be again evaporated into the martian air as water vapour. The polar caps should therefore decrease in size year by year. They have, however, so far not been seen to do so.

This annual loss of water, as well as the deficiency from the north polar cap referred to in the last chapter, is, therefore, made good in some way, and an additional water supply other than that derived from the melting polar caps must, for these reasons alone, be, consequently, somewhere available on Mars.

It was suggested in the paper referred to in the preface that such extra supply is obtainable in the extensive blue-green areas, and more especially so in the desert 'Oases' of Mars, either as natural springs or more likely from underground supplies artificially brought to the surface of the planet by artesian or deep bore wells.

The supplies so obtained would probably be either utilized locally or be, more likely, gravitated through pipes to the lowest points of the areas in which they are obtained, and thence pumped to the service reservoirs and distributed over the areas needing irrigation through the same system of pipes as are used for the distribution of water available from the melting polar caps. (See Plate V.)

The extensive blue-green areas of Mars cover about 21,000,000 square miles of its surface. The south polar cap when at its maximum covers about 10,500,000 square miles; therefore half a foot of water on the latter area would only suffice to cover the blue-green areas to a depth of 3 inches.

The north polar cap has a maximum area of 7,000,000 square miles, and the water available from it could only cover all Mars' blue-green areas to a depth of $\frac{7}{10} \times 3 = 2$ inches, supposing always that it can be fully utilized.

Such light coverings would, as we have seen, be quite inadequate for the maintenance of vegetation, and a further supply for the half-yearly irrigation of Mars' blue-green areas is clearly needed. On the assumption that a 9-inch covering in six martian months is the least which will, under the assumed conditions, suffice for the maintenance of vegetable life on Mars, the deficiencies to be made good would thus be 6 inches and 7 inches respectively.

The assumed rate of flow from the south polar cap has been taken at 10,000,000 cusecs: this is sufficient to cover all Mars' blue-green areas to a depth of 3 inches in three martian months, and would cover them to a depth of 6 inches in six martian months. The quantity of water needed for a 9-inch covering in six months from Mars' assumed underground supplies would thus be a continuous flow of 15,000,000 cusecs when the south polar cap is not melting, and therefore 5,000,000 cusecs when it is melting.

The rate of flow from the north polar cap would probably be, as already mentioned, 7,000,000 cusecs, and the amount required from Mars' underground supplies during the three months in which the north polar cap is melting would thus be 15,000,000–7,000,000, = 8,000,000 cusecs.

The constant flow throughout the year from all sources being 15,000,000 cusecs, the total number of 6-foot pipes required to carry it, with a velocity of 3·1 feet per second, would be $\frac{15,000,000}{90}$ = say 170,000; or if the pipes are grouped into 'Canals,' each consisting of 500 pipes, we should need 340 'Canals,' each about 10 miles wide, to carry the assumed flow. With 30-inch pipes and a 2 feet velocity (a 3 feet velocity being an excessive one for a pipe of this diameter) the number of 'Canals' needed would be over 3,000, whereas the actual number of 'Canals' recorded on Mars by Mr. Lowell does not much exceed 500. The assumed diameter of 6 feet cannot, therefore, be far wrong.

As the south polar cap melts, the water from it probably, as we have seen, flows northwards, overland, as a flood having a velocity of not more than 1½ feet per second, and possibly a much lower one. It is further highly probable that all the water does not so escape, but has, towards the end of the cap's melting, to be helped over the south polar island chain by being pumped through martian 'Canals,' both single and double. (See Mr. Lowell's maps and also Plate V.)

Flowing at an average rate of 1 foot per second, or say 16 miles per mundane day, the water would take $\frac{1600}{16}$ = 100 days, or about one and a half martian months, to travel from the edge

STATEMENT ILLUSTRATING DATES AND AMOUNTS OF WATER DRAWN FROM THE THREE ASSUMED SOURCES OF WATER SUPPLY ON MARS, VIZ. THE NORTH POLAR CAP, THE SOUTH POLAR CAP, AND ITS UNDERGROUND SUPPLIES.

Martian Months.	May.	June.	July.	August.	September.	October.	November.	December.	January.	February.	March.	April.	May.
Source and Amount of Water Supply.													
NORTH POLAR CAP:			7,000,000 cusecs.			Nil.			Nil.			Nil.	
SOUTH POLAR CAP:			Nil.			Nil.			10,000,000 cusecs.			Nil.	
LOCAL UNDERGROUND:			8,000,000 cusecs.			15,000,000 cusecs.			5,000,000 cusecs.			15,000,000 cusecs.	

of the melting snow to the centre of the southern seas before it could, on the floods moderating sufficiently, be used for general irrigation. If the average velocity of flow is less than 1 foot per second, as appears very likely, there would be a longer delay.

Allowing, however, for a delay of one and a half months in the southern hemisphere, and a similar one in the northern one, the required rates of flow during an entire martian year would be as shown in the statement on the preceding page.

Assuming then that a continuous flow of 15,000,000 cusecs will suffice for the full irrigation of all Mars' blue-green areas, we may proceed to try and ascertain the power which would be needed to effect this purpose when the water is pumped through pipes or conducts 6 feet in diameter at a rate of 90 cusecs per pipe or conduct.

CHAPTER VI

POWER FOR PUMPS, ETC.

THE pumping stations required to force 90 cusecs through a 6-foot diameter pipe or conduit would, on Mars (see Appendix) be about 140 miles apart on the average, and the power required at each station would be, on the average, about 1,150 N.H.P.

The total horse-power required to work the entire assumed martian irrigation system would depend on the distance the water would have to be pumped from where it is available or collecting to where it can be distributed, under a static head, from a service reservoir.

As we have seen above, the average length of each 'Canal' from collecting reservoir to service reservoir would be probably, at most, about 1,400 miles, and we should therefore require ten pumping stations of 1,150 N.H.P. on each 6-foot diameter pipe. The power required for each pipe would be thus $1{,}150 \times 10 = 11{,}500$ N.H.P.; and as to deal with a continuous flow of 15,000,000 cusecs the number of pipes needed would be 170,000, the total power required to work the entire system would be $170{,}000 \times 11{,}500 =$ say 2,000,000,000 N.H.P. Something would have to be added for the 'Canals' needed to help a portion of the water set free from both the melting polar caps from their vicinity, and we may therefore put the sum total of the power which would have to be developed at 2,500,000,000 N.H.P. This is only about four thousand times as much as that under development at the Niagara Falls alone, which is 650,000 horse-power, and much under that in daily use on our own Earth, and therefore not beyond development.

How the power needed is developed we cannot say, but as water has apparently to be artificially brought to the surface of Mars, oil-driven engines suggest themselves, the oil being obtained in a similar manner by boring for it, or power derived in some way from an unclouded sun might be in use. Power has been already so developed in Egypt.

A similar system of water carriage to that assumed to be in operation in Mars has been adopted on Earth in a locality where water is very scarce and the rainfall very light indeed.

In Western Australia 5,600,000 gallons of water are daily pumped at a rate of 10 cusecs through a 30-inch steel pipe and over a rise of 1,290 feet from a reservoir at Perth to the mining centre of Coolgardie, 351½ miles distant therefrom. Coolgardie is situated on a tableland which is one of the driest places on Earth, the maximum temperatures recorded in its neighbourhood being 132° F. in the shade and 157° F. in the sun. The distance from the storage reservoir at Perth to the service reservoir at the top of the intervening rise of 1,290 feet, whence the water gravitates under static pressure 43½ miles to Coolgardie, is 308 miles, and there are eight pumping stations in this distance, their average distance apart being thus 38½ miles. The average horse-power likely to be needed at each pumping station works out to (see Appendix) 330 N.H.P.

With eight pumping engines of this power, 5,600,000 gallons of water could on Mars be daily forced up a height of 1,290 feet through a similar 30-inch pipe line having a total length of about 680 miles (see Appendix), or more than twice the distance from Perth to the service reservoir.

If from any cause, say a great increase in the gold output, the demand for water was increased one hundredfold at Coolgardie, one hundred

30-inch pipes would be needed to meet the demand, and with the pipes 100 feet apart the width of the pipe line would be 10,000 feet, or very nearly two miles.

The Coolgardie system of water supply probably will, as time goes by, come to be more commonly adopted on Earth.

Mars' irrigation system doubtless originated in a similar small way to begin with, and has gradually been extended and enlarged until it has developed into a world-wide one, mainly intended to fully utilize the large amount of water set free in a short time twice in its year by the melting of Mars' polar caps, but one which is also used to allow of all local supplies being distributed through the existing system of pipes as well.

A 72-inch pipe, which on Earth would weigh say 21 cwt. per foot run, would on Mars weigh $\frac{21}{7} = 3$ cwt. per foot run, and could be laid there with much the same ease as a 30-inch pipe could be laid on Earth.

Given a sufficient supply of water—and many considerations point to there being large underground water supplies available in the extensive blue-green areas and desert 'Oases' of Mars—there is nothing improbable or impossible in such an irrigation system as has been suggested is most probably in operation on Mars, being in actual use on the planet.

Unless water is obtainable from the interior of Mars, its polar caps and shallow swamps (if the latter are to be there found) would alike soon cease to exist, and the planet roll through space a dead and dried-up world, which at present is certainly not the case.

Evaporation from the water so obtained and used in the irrigation of all the blue-green areas would supply the water vapour known to be present in the martian air, a portion of which vapour, when carried by the martian winds to the planet's polar regions, is there deposited, owing to the intense cold there met with, mainly in the form of ice spicules, to later on melt and be again used for irrigation.

A considerable portion of the water used for the full irrigation of the blue-green areas would filter back to the underground supplies from whence it was obtained and replenish them; there would thus be only a partial annual drain on these supplies.

For natural vegetable growth dependent on rainfall (assuming such a fall), a much larger supply of water than a 9-inch covering in six martian months would not only be needed, but a large portion of the rain falling on the surface of Mars would be wasted by falling at the wrong time and also by falling on deserts where it would be of no use. The least amount which would probably suffice would be a 24-inch fall in six martian months.

CHAPTER VII

A FINAL REVIEW

REVIEWING briefly the evidence advanced in the previous chapters for believing in the existence of a world-wide irrigation system on Mars, and noting on, adding to and strengthening it where advisable, we find that the Earth and Mars, though resembling each other in some respects, differ radically in one essential feature. On the Earth, water, when evaporated into its air as water vapour, can again return in large quantities to its entire surface in the form of rain, hail, snow, sleet, and at its polar caps ice spicules.

On Mars it cannot now return probably anywhere as rain, but is almost entirely precipitated at the polar caps, mainly in the form of ice spicules, but may be also as hail, snow, or sleet.

This difference in the precipitation of water vapour in the two worlds is the key to the riddle of Mars.

If it now only rained on Mars, as it probably once did, the existence of the extensive blue-green areas to be seen thereon could be naturally accounted for; they would, on the supposition that their colour is due to vegetation, mainly consist of wild vegetation, *i.e.* grass lands, plants, shrubs, trees and forests.

All the blue-green areas visible on Mars cover about three-eighths of its entire surface of 56,000,000 square miles, or an area of no less than 21,000,000 square miles, or more than one-third the total land surface of our own Earth, and can only, as it does not rain on Mars, show as they do on the supposition that their colour is due to crops and grasses raised as food supplies by—as Prof. Lowell was, from his observation of the planet, the first to advocate—a world-wide system of irrigation from water pumped along conduits of some sort.

That Mars' lands are irrigated twice in its year is supported by the blue-green in the southern hemisphere fading out to ochre at the summer minimum and to chocolate during its winter minimum,[1] as shown in Plate I, the irrigated lands presumably drying more at the summer minimum than at the winter one, when the soil remains wet and moist and so shows chocolate.

[1] *Mars and its Canals.* Lowell.

We have also learnt by deduction that the water required for such irrigation could be, and probably is, pumped through water-tight pipes or conduits from where it is available or collecting to neighbouring or trans-continental service reservoirs situated on relatively high points, to be thence distributed through irrigation pipes, under static pressure, all over the blue-green areas of Mars.

Here then we see that there is probably a wide distinction between mundane vegetation and martian vegetation—the one is mainly wild, the other all cultivated.

The cultivation in this way of no less than 21,000,000 square miles points to the fact that the need for crops and grasses must on Mars be great—in other words there are very likely many mouths to feed on the planet; and also indicates that Mars' blue-green areas are probably the scene of a great and ceaseless activity considerably greater than the present everyday rush of life on our own Earth.

We have further found that the original sources from which water is now obtained on the planet are its possibly extensive underground supplies, the polar caps being merely a result of evaporation from the water so obtained.

The months during which water is probably utilized from the underground supplies and the melting polar caps are indicated in the statement on page 44. These dates would probably not be rigidly adhered to, but it would be advisable to keep the underground supplies shut down as long as the water from the polar caps was available, as the latter could not well be conserved.

The 'Canal System' needed would be somewhat as shown in Plate V, which illustrates the probable systems of flow from the south pole, the north pole, and the land supplies through a few typical 'Martian Canals' (as we have imagined them to be) in a small section of Mars' entire sphere.

A comparison of this illustration with actual maps of Mars will show how close the agreement is between what would be needed and what is actually seen.

Such a close agreement will, it is hoped, leave no reasonable doubt as to the true nature of the martian 'Canals' and 'Oases.'

The two large new 'Canals' and an 'Oasis' in the neighbourhood of the Syrtis Major, reported on by Mr. Lowell in 1909,[1] would appear to point to the tapping of a new and extensive land supply from which the water, passed along these new 'Canals' to the extensive blue-green areas of the southern hemisphere, is obtained. The new

[1] *Lowell Observatory Bulletin*, No. 45.

'Canals' would very probably not show during construction, but only when they came to be irrigated or their turfed banks watered. This would account for their sudden appearance and that of the new 'Oasis' also, which, though it might have been in existence during the construction of the 'Canals,' escaped notice until their appearance directed attention to it.

The fact that both pairs of a martian 'Double Canal' show throughout their entire lengths, illustrates how flat the surface of Mars must in the main be. If water could be gravitated, at a sufficient speed, down a descending section of a 'Double Canal,' there would be no necessity for pumping stations thereon, and therefore no need for local food supplies and local irrigation, and this portion of the 'Canal' would most probably therefore not show.

A 6-foot diameter pipe should give a 90 cusec discharge on Mars with a slope in the water surface of 1 in 900 (see Appendix). The average surface slope of Mars must therefore everywhere be flatter than 1 in 1,000 and probably much flatter.

The nature of the ground over which Mars' 'Double Canals' are carried consequently very probably resembles that of Earth's rolling prairies and ordinary downs, much exaggerated. The spacing of the 'Double Canals' would thus much depend on the points from which and to which water has to be pumped over an appreciable intervening height; this height would have its ridge at much the same level throughout, and both branches of the 'Double' could be carried over it in a direct direction; except occasionally, when a handy lower dip in a ridge not in the direct line between such points has to be used and the rise surmounted by a 'Curved Double' (Plate V).

If it is admitted that 'Double Canals' intimate that on them an appreciable intervening height has to be surmounted, and that the 'Oases' mark the valleys on Mars, it will perhaps be possible to form some conception of the levels of the martian surface from their careful study, on the assumption that the average slope of the ground over which they pass is not steeper than 1 in 1,000 and probably in most cases much flatter.

In a 'Double Canal' 2,000 miles long, a central rise of 1 mile, or over 5,000 feet, could be overcome when the average upward and downward slope of the ground is 1 in 1,000. From what we know of Mars the intervening ridge is more likely to have a maximum height of 2,500 feet, thus reducing the two side slopes to 1 in 2,000. If the intervening height is not a central one, the longer side would have a slope flatter than 1 in 2,000, and the ridge which could be surmounted would be less than 2,500 feet in height, as the down slope on the far side could not, for the reason above given, well be more than 1 in 1,000.

Unless it is admitted that water is conveyed to, and distributed over, the extensive blue-green areas, the 'Oases,' and the 'Canals' of Mars in some such manner as has been above suggested, it is difficult to understand how, if they are due to vegetation, they could be maintained all the year round and be seen to wax and wane year in and year out.

A deposit of dew would certainly not be sufficient for the purpose, as the average depth of water from dew deposited on Earth amounts to only about 1·5 inches annually, and would on Mars be, most probably, considerably less; and even if we assume that sufficient water for the purpose rises unaided from the planet's interior, in the extensive blue-green areas or desert 'Oases,' we still have to face the fact that the blue-green waxes and wanes in each polar hemisphere of Mars during its winter as well as during its summer months, and to also account for the disposal of the large quantity of water twice yearly set free by the melting of Mars' polar caps, as well as to explain the observed colour changes in the martian 'Canals.'

Natural vegetable growth would depend on the sun, and die down to a considerable extent during Mars' winter months, as it does on our Earth; that the blue-green on Mars is at the height of its growth during the depth of its winter as well as at the height of its summer months irresistibly suggests that this is due to winter and summer crops which have been artificially planted and artificially raised, as is the case in many places on Earth. In India two crops are annually secured, the 'kharif' or summer crop, dependent mostly on rainfall, and the 'rabi' or winter crop, raised mostly by artificial irrigation.

This fact, that vegetation is on Mars at a maximum during both summer and winter, is a very telling point in favour of all the blue-green seen on the planet being due to cultivated crops and grasses and not to wild vegetation.

The secular changes so often noticed in the extensive blue-green areas of Mars may probably be due to large areas thereon being thrown out of cultivation for a time to allow the soil to recover. This would probably be needed most if a system analogous to dry-farming is, as appears highly probable, in use.

In trying to explain the markings on Mars, the record of every observation made of the planet's disc has to be carefully considered. Several observers have noticed the streaks crossing the continental areas of Mars broken up into a series of knots, or at times not showing at all. This may be due to the pumping stations along the pipe lines alone showing in very large telescopes, which blur small markings, when the seeing is poor and the 'Canals' and 'Oases' at a minimum, which is the case about one martian month after Mars' solstices (see Plate I); the planet making its closest approach to the Earth, when of course it is most observed, a little before it reaches in its orbit the summer solstice of its southern hemisphere.

Prof. Lowell's descriptions and drawings of what he has seen on Mars best fit in, however, with what should be the appearance of the planet if water is being pumped over its plains, downs, and dales through a world-wide system of parallel pipes sufficient in number to carry just the amount of water that has to be conveyed from low points, where it is available or collected, to higher points, from which it can be distributed under static pressure.

That we see just exactly what ought to there show is strong evidence in favour of the existence of a martian irrigation system worked on the suggested lines.

The system is a sound one, and is extensively used on a small scale on our own Earth, in the maintenance of large public gardens, such as the celebrated ones at Kew, and also elsewhere, and has also been adopted on a fairly large scale for the water supply of Coolgardie in Western Australia; Coolgardie being situated about 1,200 feet above the source of supply, and distant 351½ miles therefrom.

The construction of such a system on Mars would be no Herculean task, as the pipes could be laid and the required pumping stations erected far more easily than on Earth.

The first construction, the working and the maintenance of the system when once completed, would doubtless be an expensive matter if it were reckoned in pounds, shillings and pence; but when life itself is at stake, cost becomes a matter of no consequence whatever.

The system would be Titanic alone in the number of pipes and small pumping stations which would be required to work it.

Moderate inequalities of terrain would, as already shown, not be a bar to its successful operation.

With such a system in use every marking on Mars seen and mapped by Prof. Lowell—its 'Polar caps,' its 'Canals,' both single and double, its 'Oases,' its 'Small square blue-green areas,' its 'Carets,' and last, but not least, its 'Extensive blue-green areas; and the special feature of each marking, the melting and re-forming of the 'Polar caps,' the positions occupied by the several 'Canals,' both single and double, by the 'Oases,' the 'Square areas' and the 'Carets,' the use to which the 'Carets' are probably put, and the rhythmic waxing and waning of the 'Canals,' 'Oases,' and 'Extensive blue-green areas,' can be one and all satisfactorily accounted for.

The small white spots seen on Mars further probably mark high points where, owing to the intensive cold there met with, water vapour is deposited in the form of ice spicules, in the same way as it is deposited at the polar caps, or over which light clouds may have formed.

The universal agreement between what should show and what is actually seen is practically certain, though merely circumstantial, evidence that the 'Canals' and 'Oases' of Mars are, as they are held by Prof. Lowell and some other astronomers to be, artificial, and that they, as well as the 'Extensive blue-green areas' of Mars, are artificially irrigated by water obtained from the planet's underground supplies, which will, however, doubtless be in time exhausted. There can consequently be no reasonable doubt that there is to-day a world-wide system of irrigation in actual operation on our neighbour world—a system which, moreover, only differs in some details from that originally advocated by Mr. Lowell. How exactly the system is worked we cannot say, but very probably it is worked on the general lines already indicated.

If all this, or even a portion of what has been above advocated, is accepted, it follows that Mars is, as Prof. Lowell has for years contended, the abode of life, and that of a high order of intelligence —an intelligence which is making a fight for the life of the body in which it is lodged on exactly the same lines as would be adopted by man could he be translated to our neighbour world, and which he may be in time driven to adopt on a large scale on his present dwelling-place.

APPENDIX

CALCULATIONS

I. Flow of Water.—The formula employed on Earth for ascertaining the flow of water in pipes and channels is—

$$v^2 = \frac{2g}{m} ri \quad . \quad . \quad . \quad . \quad \text{(i)}$$

Where

v = the velocity in feet per second :

g = the force of gravity = say 32 ;

r = the hydraulic mean radius of a pipe or the hydraulic mean depth of a channel, that is the area (A) in square feet divided by the wetted perimeter (P) in feet $= \frac{A}{P}$;

i = the inclination of the water surface, or if (H) in feet = the available head and (L) in feet = the length of the pipe or channel, $i = \frac{H}{L}$; and

m = the coefficient of flow, derived by experiment for various classes of pipes and channels.

On Earth the values of m are found to depend almost entirely on the character of the wetted perimeter and on the hydraulic mean radius of the pipe or hydraulic mean depth of the channel (r), and to vary to only a very small extent with the velocity; therefore for the same class of pipe or channel the values of m for Earth and Mars will be the same; hence for Mars we have (as value of g for Mars is $\frac{3}{8} \times 32 = 12$):

$$v^2 = \frac{24}{m} ri \quad . \quad . \quad . \quad \text{(ii)}$$

whence

$$v^2 = \frac{24}{m} r \frac{H}{L}$$

or, if $H = 1$,

$$v^2 L = \frac{24}{m} r \quad . \quad . \quad . \quad \text{(iii)}$$

In a flood passing through a very wide but not deep opening, r is practically equal to $\frac{PD}{P} = D$, where D is the depth in feet.

Bazin's values of m for ordinary Earth canals taken from 'A Treatise on Hydraulics' (Unwin), page 241, are—if $r = 1, m = \cdot 029$; if $r = 2, m = \cdot 018$; if $r = 3, m = \cdot 014$; and if $r = 4, m = \cdot 012$.

For a 2 ft. depth, that is with $r = 2$, we thus have on Mars—

$$v^2 L = \frac{24}{\cdot 018} \times 2 = 2{,}600 \text{ nearly.}$$

With $v = 3, v^2 = 9$ and L for Mars = about 1 in 300 (on Earth it would be 1 in $(300 \times \frac{8}{3})$ or 1 in 800).

With $D = 4$,

$$v^2 L = \frac{24}{\cdot 012} \times 4 = 8{,}000;$$

and if $v = 1 \cdot 5$, $v^2 = 2 \cdot 25$ and L for Mars = about 1 in 3,600 (on Earth 1 in 9,600).

With a depth of 2 ft. and a water slope on Mars of 1 in 3,600 we have—

$$v^2 \times 3{,}600 = 2{,}600.$$

Whence $\quad v^2 = \cdot 70$ and $v = \cdot 84$.

The slopes in the water surfaces of pipes needed to meet given discharges are easiest ascertained from the scale given at the end of the author's 'Water Supply and Drainage Systematised and Simplified' (Longmans), substituting for Mars $\frac{8}{5}$ F = 1·6 F for F.

Thus, for a 72-inch pipe discharging 90 cusecs on Mars, we have from the scale—

$$\frac{L}{H} \times (90 \times 1{\cdot}6)^2 = 18{,}900{,}000$$

and

$$\frac{L}{H} = 913;$$

or we should need a slope in the water surface of about 1 in 900. The required slope can of course be also calculated. If we take $m = {\cdot}0044$ for a 6-foot diameter pipe—

$$v^2L = \frac{24}{{\cdot}0044} \times \frac{6}{4} = 8{,}400;$$

and as $v = 3{\cdot}1$, L = 1 in 900 nearly.

II. Pumping Stations.—The distance between pumping stations would be limited by the pressure the pipes through which the water is being pumped could stand. This on Earth is generally taken as that due to a 300 feet head of water. For pipes of similar strength it would on Mars be $300 \times \frac{8}{3} = 800$ feet, and the distance between pumping stations would thus be limited, on a horizontal pipe 6 feet in diameter discharging 90 cusecs, to $800 \times 900 = 720{,}000$ feet, or very nearly 140 miles.

The average distance between stations would be much the same if an appreciable intervening height has to be overcome, the stations being closer together on the up grade and further apart on the down grade.

III. Horse Power.—As the force of gravity on Mars is three-eighths of that on Earth, the power required to lift a given weight on Earth and Mars will be as $1^2 : \left(\frac{3}{8}\right)^2$ or as 7 to 1 very nearly; therefore the formula for ascertaining nominal horse-power on Earth becomes for Mars—

$$HP = \frac{H \times W}{33{,}000} \times \frac{1}{7} \quad . \quad . \quad \text{(iv)}$$

whence the power required to lift 90 cusecs against an 800 feet head on Mars will be:

$$HP = \frac{800 \times 90 \times 60 \times 62{\cdot}4}{33{,}000} \times \frac{1}{7}$$

$$= 1{,}150 \text{ N.H.P.};$$

on Earth it would be $1{,}150 \times 7 = 8{,}050$ N.H.P.

In the Coolgardie pipe line there is a rise of 1,290 feet and eight pumping stations; the average rise per station is thus $\frac{1290}{8} = 162$ feet. The discharge of the 30-inch main is very nearly 10 cusecs, the velocity in the pipe being taken at 2 feet per second.

To obtain this discharge we on Earth would need in the 30-inch pipe, from the scale above referred to—

as $\qquad \frac{L}{H} \times 10^2 = 212{,}000,$

whence $\qquad \frac{L}{H} = 2{,}120,$

a slope in the water surface of 1 in 2,120.

As the average distance between pumping stations is $38\frac{1}{2}$ miles or 206,480 feet, the total head needed in this distance to give this slope would be $\frac{206{,}480}{2{,}120} =$ about 100 feet; the total head to be pumped against would thus be $162 + 100 = 262$ feet, and the power required at each station from

$$HP = \frac{262 \times 10 \times 60 \times 62{\cdot}4}{33{,}000}$$

would be about 330 N.H.P.

With engines of this power at eight separate pumping stations, the 10 cusecs could on Mars be pumped through a 30-inch pipe of similar strength up a height of 1,290 feet for a total distance of 680 miles, as the following calcluation shows—

To discharge 10 cusecs, the slope needed in the 30-inch pipe would on Mars be, from

$$\frac{L}{H} (10 \times 1{\cdot}6)^2 = 212{,}000,$$

whence $$\frac{L}{H} \text{ about } = 830,$$

one of 1 in 830.

The total head which could be pumped against between stations would from $262 \times \frac{8}{3}$ be 700 feet. The head available to overcome friction in the pipe would thus be $700 - 162 = 538$ feet, and the distance between pumping stations could be $830 \times 538 = 446{,}540$ feet, or, say, 85 miles. The total distance the 10 cusecs could be pumped would therefore be $85 \times 8 = 680$ miles.

C E. H.

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